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(54) Title: ANTAGONISTS OF NEUROFILIN RECEPTOR FUNCTIONAL AND USE THEREOF		
(57) Abstract <p>The present invention relates to antagonists of neuropilin receptor function and use thereof in the treatment of cancer, particularly metastatic cancer, and angiogenic diseases.</p>		

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ANTAGONISTS OF NEUROPILIN RECEPTOR FUNCTION AND USE THEREOF
STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

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5 FIELD OF THE INVENTION

The present invention relates to antagonists of neuropilin receptor function and use thereof in the treatment of cancer, particularly metastatic cancer, and angiogenic diseases.

10 BACKGROUND OF THE INVENTION

Cancer, its development and treatment is a major health concern. The standard treatments available are few and directed to specific types of cancer, and provide no absolute guarantee of success. Most treatments rely on an approach that involves killing off rapidly growing cells in the hope that rapidly growing cancerous cells will succumb, either to the treatment, or at least be sufficiently reduced in numbers to allow the body's system to eliminate the remainder. However most, of these treatments are non-specific to cancer cells and adversely effect non-malignant cells. Many cancers although having some phenotype relationship are quite diverse. Yet, what treatment works most effectively for one cancer may not be the best means for treating another cancer. Consequently, an appreciation of the severity of the condition must be made before beginning many therapies. In order to most effective, these treatments require not only an early detection of the malignancy, but an appreciation of the severity of the malignancy. Currently, it can be difficult to distinguish cells at a molecular level as it relates to effect on treatment. Thus, methods of being able to screen malignant cells and better understand their disease state are desirable.

While different forms of cancer have different properties, one factor which many cancers share is that they can metastasize. Until such time as metastasis occurs, a tumor, although it may be malignant, is confined to one area of the body. This may cause discomfort and/or pain, or even lead to more serious problems including death, but if it can be located, it may be surgically removed and, if done with adequate care, be treatable. However, once metastasis sets in, cancerous cells have invaded the body and while surgical resection may remove the parent tumor, this does not address other tumors. Only chemotherapy, or some particular form of targeting therapy, then stands any chance of success.

The process of tumor metastasis is a multistage event involving local invasion and destruction of intercellular matrix, intravasation into blood vessels, lymphatics or other channels of transport, survival in the circulation, extravasation out of the vessels in the secondary site and growth in the new location (Fidler, et al., *Adv. Cancer Res.* 28, 149-250 (1978), Liotta, et al., *Cancer Treatment Res.* 40, 223-238 (1988), Nicolson, *Biochim. Biophys. Acta* 948, 175-224 (1988) and Zetter, *N. Eng. J. Med.* 322, 605-612 (1990)). Success in establishing metastatic deposits requires tumor cells to be able to accomplish these steps sequentially. Common to many steps of the metastatic process is a requirement for motility. The enhanced movement of malignant tumor cells is a major contributor to the progression of the disease toward metastasis. Increased cell motility has been associated with enhanced metastatic potential in animal as well as human tumors (Hosaka, et al., *Gann* 69, 273-276 (1978) and Haemmerlin, et al., *Int. J. Cancer* 27, 603-610 (1981)).

Identifying factors that are associated with onset of tumor metastasis is extremely important. In addition, to using such factors for diagnosis and prognosis, those factors are an important site for identifying new compounds that can be used for treatment and as a target for treatment identifying new modes of treatment such as inhibition of metastasis is highly desirable.

Tumor angiogenesis is essential for both primary tumor expansion and metastatic tumor spread, and angiogenesis itself requires ECM degradation (Blood et al., *Biochim. Biophys. Acta* 1032:89-118 (1990)). Thus, malignancy is a systemic disease in which interactions between the neoplastic cells and their environment play a

crucial role during evolution of the pathological process (Fidler, I. J., *Cancer Metastasis Rev.* 5:29-49 (1986)).

There is mounting evidence that VEGF may be a major regulator of angiogenesis (reviewed in Ferrara, et al., *Endocr. Rev.*, 13, 18-32 (1992); Klagsbrun, et al., *Curr. Biol.*, 3, 699-702 (1993); Ferrara, et al., *Biochem. Biophys. Res. Commun.*, 161, 851-858 (1989)). VEGF was initially purified from the conditioned media of folliculostellate cells (Ferrara, et al., *Biochem. Biophys. Res. Commun.*, 161, 851-858 (1989)) and from a variety of tumor cell lines (Myoken, et al., *Proc. Natl. Acad. Sci. USA*, 88:5819-5823 (1991); Plouet, et al., *EMBO. J.*, 8:3801-3806 (1991)). VEGF was found to be identical to vascular permeability factor, a regulator of blood vessel permeability that was purified from the conditioned medium of U937 cells at the same time (Keck, et al., *Science*, 246:1309-1312 (1989)). VEGF is a specific mitogen for endothelial cells (EC) *in vitro* and a potent angiogenic factor *in vivo*. The expression of VEGF is up-regulated in tissue undergoing vascularization during embryogenesis and the female reproductive cycle (Brier, et al., *Development*, 114:521-532 (1992); Shweiki, et al., *J. Clin. Invest.*, 91:2235-2243 (1993)). High levels of VEGF are expressed in various types of tumors, but not in normal tissue, in response to tumor-induced hypoxia (Shweiki, et al., *Nature* 359:843-846 (1992); Dvorak et al., *J. Exp. Med.*, 174:1275-1278 (1991); Plate, et al., *Cancer Res.*, 53:5822-5827; Ikea, et al., *J. Biol. Chem.*, 270:19761-19766 (1986)). Treatment of tumors with monoclonal antibodies directed against VEGF resulted in a dramatic reduction in tumor mass due to the suppression of tumor angiogenesis (Kim, et al., *Nature*, 382:841-844 (1993)). VEGF appears to play a principle role in many pathological states and processes related to neovascularization. Regulation of VEGF expression in affected tissues could therefore be key in treatment or prevention of VEGF induced neovascularization/angiogenesis.

VEGF exists in a number of different isoforms that are produced by alternative splicing from a single gene containing eight exons (Ferrara, et al., *Endocr. Rev.*, 13:18-32 (1992); Tischer, et al., *J. Biol. Chem.*, 806:11947-11954 (1991); Ferrara, et al., *Trends Cardio Med.*, 3:244-250 (1993); Polterak, et al., *J. Biol. Chem.*, 272:7151-7158 (1997)). Human VEGF isoforms consists of monomers of 121, 145, 165, 189,

and 206 amino acids, each capable of making an active homodimer (Polterak et al., *J. Biol. Chem.*, 272:7151-7158 (1997); Houck, et al., *Mol. Endocrinol.*, 8:1806-1814 (1991)). The VEGF₁₂₁ and VEGF₁₆₅ isoforms are the most abundant. VEGF₁₂₁ is the only VEGF isoforms that does not bind to heparin and is totally secreted into the culture medium. VEGF₁₆₅ is functionally different than VEGF₁₂₁ in that it binds to heparin and cell surface heparin sulfate proteoglycans (HSPGs) and is only partially released into the culture medium (Houck, et al., *J. Biol. Chem.*, 247:28031-28037 (1992); Park, et al., *Mol. Biol. Chem.*, 4:1317-1326 (1993)). The remaining isoforms are entirely associated with cell surface and extracellular matrix HSPGs (Houck, et al., *J. Biol. Chem.*, 247:28031-28037 (1992); Park, et al., *Mol. Biol. Chem.*, 4:1317-1326 (1993)).

VEGF receptor tyrosine kinases, KDR/Flk-1 and/or Flt-1, are mostly expressed by EC (Terman, et al., *Biochem. Biophys. Res. Commun.*, 187:1579-1586 (1992); Shibuya, et al., *Oncogene*, 5:519-524 (1990); De Vries, et al., *Science*, 265:989-991 (1992); Gitay-Goran, et al., *J. Biol. Chem.*, 267:6003-6096 (1992); Jakeman, et al., *J. Clin. Invest.*, 89:244-253 (1992)). It appears that VEGF activities such as mitogenicity, chemotaxis, and induction of morphological changes are mediated by KDR/Flk-1 but not Flt-1, even though both receptors undergo phosphorylation upon binding of VEGF (Millauer, et al., *Cell*, 72:835-846 (1993); Waltenberger, et al., *J. Biol. Chem.*, 269:26988-26995 (1994); Seetharam, et al., *Oncogene*, 10:135-147 (1995); Yoshida, et al., *Growth Factors*, 7:131-138 (1996)). Recently, Soker et al., identified a new VEGF receptor which is expressed on EC and various tumor-derived cell lines such as breast cancer-derived MDA-MB-231 (231) cells (Soker, et al., *J. Biol. Chem.*, 271:5761-5767 (1996)). This receptor requires the VEGF isoform to contain the portion encoded by exon 7. For example, although both VEGF₁₂₁ and VEGF₁₆₅R bind to KDR/Flk-1 and Flt-1, only VEGF₁₆₅ binds to the new receptor. Thus, this is an isoform-specific receptor and has been named the VEGF₁₆₅ receptor (VEGF₁₆₅R). It will also bind the 189 and 206 isoforms. VEGF₁₆₅R has a molecular mass of approximately 130 kDa, and it binds VEGF₁₆₅ with a K_d of about 2×10^{-10} M, compared with approximately 5×10^{-12} M for KDR/Flk-1. In structure-function analysis, it was shown directly that VEGF₁₆₅ binds to VEGF₁₆₅R via its exon 7-

encoded domain which is absent in VEGF₁₂₁ (Soker, et al., *J. Biol. Chem.*, 271:5761-5767 (1996)). However, the function of the receptor was unclear.

Identifying the alterations in gene expression which are associated with malignant tumors, including those involved in tumor progression and angiogenesis, is clearly a prerequisite not only for a full understanding of cancer, but also to develop new rational therapies against cancer.

A further problem arises, in that the genes characteristic of cancerous cells are very often host genes being abnormally expressed. It is quite often the case that a particular protein marker for a given cancer while expressed in high levels in connection with that cancer is also expressed elsewhere throughout the body, albeit at reduced levels.

The current treatment of angiogenic diseases is inadequate. Agents which prevent continued angiogenesis, e.g, drugs (TNP-470), monoclonal antibodies, antisense nucleic acids and proteins (angiostatin and endostatin) are currently being tested. See, Battegay, *J. Mol. Med.*, 73, 333-346 (1995); Hanahan et al., *Cell*, 86, 353-364 (1996); Folkman, *N. Engl. J. Med.*, 333, 1757-1763 (1995). Although preliminary results with the antiangiogenic proteins are promising, there is still a need for identifying genes encoding ligands and receptors involved in angiogenesis for the development of new antiangiogenic therapies.

SUMMARY OF THE INVENTION

We have isolated a cDNA encoding the VEGF₁₆₅ R gene (SEQ ID NO: 1) and have deduced the amino acid sequence of the receptor (SEQ ID NO:2) We have discovered that this novel VEGF receptor is structurally unrelated to Flt-1 or KDR/Flk-1 and is expressed not only by endothelial cells but by non-endothelial cells, including surprisingly tumor cells.

In ascertaining the function of the VEGF₁₆₅R we have further discovered that this receptor has been identified as a cell surface mediator of neuronal cell guidance and called neuropilin-1. Kolodkin et al., *Cell* 90:753-762 (1997). We refer to the receptor as VEGF₁₆₅R/NP-1 or NP-1.

In addition to the expression cloning of VEGF₁₆₅R/NP-1 cDNA we isolated another human cDNA clone whose predicted amino acid sequence was 47% homologous to that of VEGF₁₆₅R/NP-1 and over 90% homologous to rat neuropilin-2 (NP-2) which was recently cloned (Kolodkin, et al., *Cell* 90, 753-762 (1997)).

5 Our results indicate that VEGF₁₆₅R/NP-1 and NP-2 are expressed by both endothelial and tumor cells. (Fig. 19) We have shown that endothelial cells expressing both KDR and VEGF₁₆₅R/NP-1 respond with increased chemotaxis towards VEGF₁₆₅, not VEGF₁₂₁, when compared to endothelial cells expressing KDR alone. While not wishing to be bound by theory, we believe that VEGF₁₆₅R/NP-1 functions in
10 endothelial cells to mediate cell motility as a co-receptor for KDR.

We have also shown in the Boyden chamber motility assay that VEGF₁₆₅ stimulates 231 breast carcinoma cell motility in a dose-response manner (Fig 15A). VEGF₁₂₁ had no effect motility of these cells (Fig 15B). Since tumor cells such as, 231 cells, do not express the VEGF receptors, KDR or Flt-1, while not wishing to be
15 bound by theory, we believe that tumor cells are directly responsive to VEGF₁₆₅ via VEGF₁₆₅R/NP-1.

We have also analyzed two variants of Dunning rat prostate carcinoma cells, AT2.1 cells, which are of low motility and low metastatic potential, and AT3.1 cells, which are highly motile, and metastatic. Cross-linking and Northern blot analysis
20 show that AT3.1 cells express abundant VEGF₁₆₅R/NP-1, capable of binding VEGF₁₆₅, while AT2.1 cells don't express VEGF₁₆₅R/NP-1 (Fig 18). Immunostaining of tumor sections confirmed the expression of VEGF₁₆₅R/NP-1 in AT3.1, but not AT2.1 tumors (Fig 17). Additionally, immunostaining showed that in subcutaneous AT3.1 and PC3 tumors, the tumor cells expressing VEGF₁₆₅R/NP-1 were found
25 preferentially at the invading front of the tumor/dermis boundary (Fig 17). Furthermore, stable clones of AT2.1 cells overexpressing VEGF₁₆₅R/NP-1 had enhanced motility in the Boyden chamber assay. These results indicate that neuropilin expression on tumor cells is associated with the motile, metastatic phenotype and angiogenesis, and thus is an important target for antiangiogenic and anticancer
30 therapy.

The present invention relates to antagonists of neuropilin (NP) receptor function that can be use to inhibit metastasis and angiogenesis. Antagonists of invention can block the receptor preventing ligand binding, disrupt receptor function, or inhibit receptor occurrence. Specific antagonists include, for example, compounds that bind to NP-1 or NP-2 and antibodies that specifically binds the receptor at a region that inhibits receptor function. For example, one can add an effective amount of a compound that binds to NP-1 to disrupt receptor fuction and thus inhibit metastasis.

We have surprisingly discovered that members of the semaphorin/collapsins family are not only inhibitors of neuronal guidance but also inhibitors of endothelial and tumor cell motility in cells that express neuropilin. Accordingly, preferred antagonists include members of the semaphorin/collapsins family or fragments thereof that bind NP and have VEGF antagonist activity as determined, for example, by the human umbilical vein endothelial cell (HUVEC) proliferation assay using VEGF₁₆₅ as set forth in Soker et al., *J. Biol. Chem.* 272, 31582-31588 (1997). Preferably, the semaphorin/collapsin has at least a 25% reduction in HUVEC proliferation, more preferably a 50% reduction, even more preferably a 75% reduction, most preferably a 95% reduction.

VEGF antagonist activity of the semaphorin/collapsin may also be determined by inhibition of binding of labeled VEGF₁₆₅ to VEGF₁₆₅R as disclosed in Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)) or to PAE/NP cells. Preferably, the portion inhibits binding by at least 25%, more preferably 50%, most preferably 75%.

In accordance with the present invention, neuropilin antagonists, or nucleic acids, e.g., DNA or RNA, encoding such antagonists, are useful as inhibitors of VEGF and NP function and can be used to treat diseases, disorders or conditions associated with VEGF and NP expression. The antagonists can be used alone or in combination with other anti-VEGF strategies including, for example, those that antagonize VEGF directly (e.g. anti-VEGF antibodies, soluble VEGF receptor extracellular domains), or antagonize VEGF receptors (e.g. anti-KDR antibodies, KDR kinase inhibitors, dominant-negative VEGF receptors) (Presta LG, et al., *Cancer Res.* 57: 4593-4599 (1997), Kendall RL, et al., (1996) *Biochem. Biophys. Res. Commun.* 226: 324-328,

Goldman CK, et al., (1998) Proc. Natl. Acad. Sci. USA 95: 8795-8800, Strawn LM, et al., (1996) Cancer Res. 56: 3540-3545, Zhu Z, et al., (1998). Cancer Res. 58: 3209-3214, Witte L, et al., (1998). Cancer Metastasis Rev. 17: 155-161.)

5 Diseases, disorders, or conditions, associated with VEGF, include, but are not limited to retinal neovascularization, hemangiomas, solid tumor growth, leukemia, metastasis, psoriasis, neovascular glaucoma, diabetic retinopathy, rheumatoid arthritis, endometriosis, mucular degeneration, osteoarthritis, and retinopathy of prematurity (ROP).

10 In another embodiment, one can use isolated VEGF₁₆₅R/NP-1 or NP-2 or cells expressing these receptors in assays to discover compounds that bind to or otherwise interact with these receptors in order to discover NP antagonists that can be used to inhibit metastasis and/or angiogenesis.

Other aspects of the invention are disclosed *infra*.

15 BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows purification of VEGF₁₆₅R From 231 Cells.

125I-VEGF₁₆₅ (5 ng/ml) was bound and cross-linked to receptors on 231 cells and analyzed by SDS PAGE and autoradiography (lane 1). VEGF₁₆₅R was purified by Con A and VEGF₁₆₅ affinity column chromatography and analyzed by SDS-PAGE and silver stain (lane 2). Two prominent bands were detected (arrows) and N-terminally sequenced separately. Their N-terminal 18 amino acid sequences are shown to the right of the arrows. The published N-terminal sequences of human and mouse neuropilin (Kawakami et al., *J. Neurobiol.*, 29, 1-17 (1995); He and Tessier-Lavigne, *Cell* 90, 739-751 1997) are shown below (SEQ ID NOS: 5 and 6).

25

Figures 2A and 2B show isolation of VEGF₁₆₅R cDNA by Expression Cloning. Photomicrographs (dark field illumination) of COS 7 cells binding 125I-VEGF₁₆₅. 125I-VEGF₁₆₅ was bound to transfected COS 7 cells which were then washed, fixed, and overlaid with photographic emulsion that was developed as described in the example, *infra*.

30

Figure 2A shows COS 7 cells were transfected with a primary plasmid pool (#55 of the 231 cell library) representing approximately 3×10^3 clones and one COS 7 cell binding ^{125}I -VEGF₁₆₅ in the first round of screening is shown.

Figure 2 shows several COS 7 cells transfected with a single positive cDNA clone (A2) binding ^{125}I -VEGF₁₆₅ after the third round of screening.

Figure 3 shows the Deduced Amino Acid Sequence of Human VEGF₁₆₅R/NP-1 (SEQ ID NO:3). The deduced 923 amino acid sequence of the open reading frame of VEGF₁₆₅R/NP-1, clone A2 (full insert size of 6.5 kb) is shown. The putative signal peptide sequence (amino acids 1-21) and the putative transmembrane region (amino acids 860-883) are in boxes. The amino acid sequence obtained by N-terminal amino acid sequencing (Figure 3, amino acids 22-39) is underlined. The arrow indicates where the signal peptide has been cleaved and removed, based on comparison of the N-terminal sequence of purified VEGF₁₆₅R/NP-1 and the cDNA sequence. The sequence of human VEGF₁₆₅R/NP-1 reported here differs from that reported by He et al. (He and Tessier-Lavigne, *Cell* 90, 739-751 (1997)) in that we find Lys₂₆ rather than Glu₂₆, and Asp₈₅₅ rather than Glu₈₅₅. Lys₂₆ and Asp₈₅₅ are found, however, in mouse and rat VEGF₁₆₅R/NP-1 (Kwakami et al., *J. Neurobiol.* 29, 1-17 (1995); He and Tessier-Lavigne, *Cell* 90, 739-751 (1997)).

Figures 4A and 4B show the Comparison of the Deduced Amino Acid Sequence of Human VEGF₁₆₅R/NP-1 (SEQ ID NO:2) and NP-2 (SEQ ID NO:4). The deduced open reading frame amino acid sequences of VEGF₁₆₅R/NP-1 and NP-2 are aligned using the DNASIS program. Amino acids that are identical in both open reading frames are shaded. The overall homology between the two sequences is 43%.

Figure 5 shows a Northern Blot Analysis of VEGF₁₆₅R/NP-1 Expression in Human EC and Tumor-Derived Cell Lines. Total RNA samples prepared from HUVEC (lane 1) and tumor-derived breast carcinoma, prostate carcinoma and melanoma cell lines as indicated (lanes 2-8) were resolved on a 1% agarose gel and blotted onto a GeneScreen nylon membrane. The membrane was probed with ^{32}P -

labeled VEGF₁₆₅R/NP-1 cDNA and exposed to X-ray film. Equal RNA loading was demonstrated by ethidium bromide staining of the gel prior to blotting. A major species of VEGF₁₆₅R/NP-1 mRNA of approximately 7 kb was detected in several of the cell lines.

5

Figure 6 shows a Northern Blot Analysis of VEGF₁₆₅R/NP-1 and KDR mRNA in Adult Human Tissues. A pre-made Northern blot membrane containing multiple samples of human mRNA (Clontech) was probed with ³²P-labeled VEGF₁₆₅R/NP-1 cDNA (top) as described in Fig 5, and then stripped and reprobed with ³²P-labeled KDR cDNA (bottom).

10

Figures 7A and 7B show a Scatchard Analysis of VEGF₁₆₅ binding to VEGF₁₆₅R/NP-1. Figure 7A. Increasing amounts of ¹²⁵I-VEGF₁₆₅ (0.1-50 ng/ml) were added to subconfluent cultures of PAE cells transfected with human VEGF₁₆₅R/NP-1 cDNA (PAE/NP-1 cells) in 48 well dishes. Non-specific binding was determined by competition with a 200-fold excess of unlabeled VEGF₁₆₅. After binding, the cells were washed, lysed and the cell-associated radioactivity was determined using a γ counter.

15

Figure 7B. The binding data shown in Figure 7A were analyzed by the method of Scatchard, and a best fit plot was obtained with the LIGAND program (Munson and Rodbard, 1980). PAE/NP-1 cells express approximately 3 X 10⁵ VEGF₁₆₅ binding sites per cell and bind ¹²⁵I-VEGF₁₆₅ with a K_d of 3.2 X 10⁻¹⁰ M.

20

Figure 8 shows cross-linking of VEGF₁₆₅ and VEGF₁₂₁ to PAE cells Expressing VEGF₁₆₅R/NP-1 and/or KDR. ¹²⁵I-VEGF₁₆₅ (5 ng/ml) (lanes 1-6) or ¹²⁵I-VEGF₁₂₁ (10 ng/ml) (lanes 7-10) were bound to subconfluent cultures of HUVEC (lane 1), PC3 (lane 2), PAE (lanes 3 and 7), a clone of PAE cells transfected with human VEGF₁₆₅R/NP-1 cDNA (PAE/NP-1) (lanes 4 and 8), a clone of PAE cells transfected with KDR (PAE/KDR) (lanes 5 and 9), and a clone of PAE/KDR cells transfected with human VEGF₁₆₅R/NP-1 cDNA (PAE/KDR/NP-1) (lanes 6 and 10).

30

The binding was carried out in the presence of 1 µg/ml heparin. At the end of a 2 hour incubation, each ¹²⁵I-VEGF isoform was chemically cross-linked to the cell surface.

The cells were lysed and proteins were resolved by 6% SDS-PAGE. The polyacrylamide gel was dried and exposed to X-ray film. Solid arrows denote radiolabeled complexes containing ¹²⁵I-VEGF and KDR, open arrows denote radiolabeled complexes containing ¹²⁵I-VEGF and VEGF₁₆₅R/NP-1.

Figure 9 shows cross linking of VEGF₁₆₅ to PAE/KDR Cells Co-expressing VEGF₁₆₅R/NP-1 Transiently. PAE/KDR cells were transfected with pCPhygro or pCPhyg-NP-1 plasmids as described in "Experimental Procedures", and grown for 3 days in 6 cm dishes. ¹²⁵I-VEGF₁₆₅ (5 ng/ml) was bound and cross linked to parental PAE/KDR cells (lane 1), to PAE/KDR cells transfected with pCPhygro vector control (V) (lane 2), to PAE/KDR cells transfected with pCPhyg- VEGF₁₆₅R/NP-1 plasmids (VEGF₁₆₅R/NP-1) (lane 3), and to HUVEC (lane 4).). The binding was carried out in the presence of 1 µg/ml heparin. The cells were lysed and proteins were resolved by 6% SDS-PAGE as in Figure 8. Solid arrows denote radiolabeled complexes containing ¹²⁵I-VEGF₁₆₅ and KDR. Open arrows denote radiolabeled complexes containing ¹²⁵I-VEGF₁₆₅ and VEGF₁₆₅R/NP-1.

Figure 10 shows inhibition of ¹²⁵I-VEGF₁₆₅ binding to VEGF₁₆₅R/NP-1 interferes with its binding to KDR. ¹²⁵I-VEGF₁₆₅ (5 ng/ml) was bound to subconfluent cultures of PAE transfected with human VEGF₁₆₅R/NP-1 cDNA (PAE/NP-1) (lanes 1 and 2), PAE/KDR cells (lanes 3 and 4), and PAE/KDR cells transfected with human VEGF₁₆₅R/NP-1 cDNA (PAE/KDR/NP-1) (lanes 5 and 16) in 35 mm dishes. The binding was carried out in the presence (lanes 2, 4, and 6) or the absence (lanes 1, 3, and 5) of 25 µg/ml GST-Ex 7+8. Heparin (1 µg/ml) was added to each dish. At the end of a 2 hour incubation, ¹²⁵I-VEGF₁₆₅ was chemically cross-linked to the cell surface. The cells were lysed and proteins were resolved by 6% SDS-PAGE as in Figure 9. Solid arrows denote radiolabeled complexes containing

^{125}I -VEGF₁₆₅ and KDR, open arrows denote radiolabeled complexes containing ^{125}I -VEGF₁₆₅ and VEGF₁₆₅R/NP-1.

Figures 11A-C show a model for VEGF₁₆₅R/NP-1 modulation of VEGF₁₆₅ Binding to KDR. 11A. Cells expressing KDR alone. 11B. Cells co-expressing KDR and VEGF₁₆₅R/NP-1. 11C. Cells co-expressing KDR and VEGF₁₆₅R/NP-1 in the presence of GST-Ex 7+8 fusion protein.

A single KDR receptor or a KDR-VEGF₁₆₅R/NP-1 pair is shown in top portion. An expanded view showing several receptors is shown in the bottom portion. VEGF₁₆₅ binds to KDR via exon 4 and to VEGF₁₆₅R/NP-1 via exon 7 (Keyt et al. *J. Biol. Chem.* 271, 5638-5646 (1996b); Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)). A rectangular VEGF₁₆₅ molecule represents a suboptimal conformation that doesn't bind to KDR efficiently while a rounded VEGF₁₆₅ molecule represents one that fits better into a binding site. In cells expressing KDR alone, VEGF₁₆₅ binds to KDR in a sub-optimal manner. In cells co-expressing KDR and VEGF₁₆₅R/NP-1, the binding efficiency of VEGF₁₆₅ to KDR is enhanced. It may be that the presence of VEGF₁₆₅R/NP-1 increases the concentration of VEGF₁₆₅ on the cell surface, thereby presenting more growth factor to KDR. Alternatively, VEGF₁₆₅R/NP-1 may induce a change in VEGF₁₆₅ conformation that allows better binding to KDR, or both might occur. In the presence of GST-Ex 7+8, VEGF₁₆₅ binding to VEGF₁₆₅R/NP-1 is competitively inhibited and its binding to KDR reverts to a sub-optimal manner.

Figure 12 shows the human NP-2 amino acid sequence (SEQ ID NO:4).

Figures 13A, 13B and 13C show the human NP-2 DNA sequence (SEQ ID NO:3).

Figures 14A, 14B, 14C, 14D, 14E and 14F show the nucleotide (SEQ ID NO:1) and amino acid sequences (SEQ ID NO:2) of VEGF₁₆₅R/NP-1.

Figures 15A and 15B show VEGF₁₆₅ stimulation of MDA MB 231 cell motility. (Figure 15A) Dose response of VEGF₁₆₅ motility activity. (Figure 15B) Both VEGF₁₆₅ and bFGF stimulate motility but VEGF₁₂₁ does not.

5 Figures 16A, 16B and 16C show motility and neuropilin-1 expression of Dunning rat prostate carcinoma cell lines AT3-1 (high motility, high metastatic potential) and AT2.1 (low motility, low metastatic potential) cells. (Figure 16A) AT3.1 cells are more motile than AT2.1 cells in a Boyden chamber assay. 125I-VEGF₁₆₅ cross-links neuropilin-1 on AT3.1 cells but does not cross-link to AT2.1
10 cells. (Figure 16C) AT3.1 but not AT2.1 cells express neuropilin-1, while both cell types express VEGF.

Figures 17A, 17B and 17C show immunostaining of (Figure 17A) a PC3 subcutaneous tumor in a nude mouse, (Figure 17B) an AT3.1 tumor in a rat, (Figure
15 17C) an AT2.1 tumor in rat with anti-neuropilin-1 antibodies. Neuropilin immunostaining is preferentially associated with PC3 and AT3.1 tumor cells at the tumor/dermis boundary. Some of these cells cluster around blood vessels. AT2.1 cells do not express neuropilin-1.

20 Figures 18A and 18B show overexpression of neuropilin-1 in AT2.1 cells. (Figure 18A) Western blot, (Figure 18B) motility activity. Three AT2.1 clones (lanes 4,5,6) express higher amounts of neuropilin-1 protein and are more motile compared to parental AT2.1 cells or AT2.1 vector (AT2.1/V) controls and approach AT3.1 cell neuropilin-1 levels and migration activity.

25 Figure 19 shows expression of NP-1, NP-2 and β -actin in cancer cell lines and endothelial cells using reverse transcriptase PCR following primers:

Human NP-1
Forward (328-351): 5' TTTCGCAACGATAAATGTGGCGAT 3' (SEQ ID NO:7)
30 Reverse (738-719): 5' TATCACTCCACTAGGTGTTG 3' (SEQ ID NO:8)
Human NP-2
Forward (513-532): 5' CCAACCAGAAGATTGTCCTC 3' (SEQ ID NO:9)
Reverse (1181-1162): 5' GTAGGTAGATGAGGCACTGA 3' (SEQ ID NO:10)

Figure 20 shows the effects of collapsin-1 treatment on PAE cell motility in a Boyden chamber. Collapsin-1 inhibits, by about 65% the basal migration of PAE cells expressing neuropilin-1 but not PAE cells expressing KDR. alone One collapsin unit is about 3 ng/ml.

Figures 21A and 21B show results of the aortic ring assay. Collapsin was added (Fig. 21A) or not added (Fig. 21B) to a segment of rat aortic ring and the migration of endothelial cells out of the rings and their formation of tubes was monitored after a week in organ culture. Migration and tube formation are inhibited by collapsin-1.

DETAILED DESCRIPTION OF THE INVENTION

We have discovered that there are VEGF receptors (VEGFR) and neuropilins such as VEGF₁₆₅R/NP-1 and NP-2 that are associated with metastatic potential of a malignant cell and angiogenesis. As used herein, "neuropilin" includes not only VEGF₁₆₅R/NP-1 and NP-2 but any neuropilin or VEGFR, where the constituents share at least about 85% homology with either of the above VEGF₁₆₅R/NP-1 and NP-2 can be used. More preferably, such constituent shares at least 90% homology. Still more preferably, each constituent shares at least 95% homology.

Homology is measured by means well known in the art. For example % homology can be determined by any standard algorithm used to compare homologies. These include, but are not limited to BLAST 2.0 such as BLAST 2.0.4 and i. 2.0.5 available from the NIH (See www.ncbi.nlm.nih.gov/BLAST/newblast.html) (Altschul, S.F., et al. Nucleic Acids Res. 25: 3389-3402 (1997)) and DNASIS (Hitachi Software Engineering America, Ltd.). These programs should preferably be set to an automatic setting such as the standard default setting for homology comparisons. As explained by the NIH, the scoring of gapped results tends to be more biologically meaningful than ungapped results.

For ease of reference, this disclosure will generally talk about VEGF₁₆₅R/NP-1 and NP-2 and/or homologs thereof but all teaching are applicable to the above-described homologs.

5 In another embodiment a VEGFR can be used as long as it binds to a sequence having at least 90%, more preferably 95% homology to exon 7 of VEGF₁₆₅. These VEGF receptors and neuropilins, e.g., VEGF₁₆₅R/NP-1 and NP-2, are associated with both tumor metastases and angiogenesis. We have shown that expression of VEGF₁₆₅R/NP-1 and NP-2 is upregulated in highly metastatic prostate cancer cell lines relative to poorly metastatic or nonmetastatic lines. Thus, expression
10 of VEGF₁₆₅R/NP-1 and NP-2 is associated with a tumors metastatic potential.

X In accordance with the present invention, antagonists of neuropilin receptor function can be used inhibit or prevent the metastasis process and/or angiogenesis. Antagonists of the invention can block the receptors preventing ligand binding, disrupt receptor function, or inhibit receptor occurrence. Specific antagonists include, for
15 example, compounds that bind to NP-1 or NP-2 and antibodies that specifically binds the receptor at a region that inhibits receptor function. For example, one can add an effective amount of a compound that binds to NP-1 to disrupt receptor fuction and thus inhibit metastasis.

Preferred antagonists include members of the semaphorin/collapsins family.
20 We have surprisingly discovered that members of the semaphorin/collapsins family are not only inhibitors of neuronal guidance but also inhibitors of endothelial and tumor cell motility in cells that express neuropilin. Collapsin-1 is a particularly preferred antagonist. Other members of the semaphorin collapsin family can be selected by screening for neuropilin binding.

25 Semaphorin/collapsins are a family of 100 kDa glycoproteins (Luo, et al. (1993) *Cell* 75: 217-227; Kolodkin, et al., (1993) *Cell* 75: 1389-1399, Behar, et al., (1996) *Nature* 383: 525-528.) Semaphorins are the mammalian homologue and collapsins are the chick homologue. Semaphorins are expressed primarily in the developing CNS, but are also found in developing bones and heart. The receptors for
30 the semaphorins are neuropilin-1 and neuropilin-2 (He, et al., *Cell* 90, 739-751 (1997), Kolodkin, et al, *Cell* 90, 753-762 (1997)) and there is ligand binding

specificity for different semaphorin family members (Chen, et al., *Neuron* 19:547-559 (1997)). The K_d for semaphorin binding is about 3×10^{-10} M, similar to that for VEGF₁₆₅ binding to neuropilin-1. Semaphorins mediate neuronal guidance by repelling and collapsing advancing dorsal root ganglion (DRG) growth cones.

5 Semaphorin/collapsins are known in the art and can be isolated from natural sources or produced using recombinant DNA methods. See, for example, U.S. Patent 5,807,826. Additionally, fragments of the semaphorin/collapsins may be used. For example, a 70 amino acid region within the semaphorin domain specifies the biological activities of three collapsin family members (Koppel, et al., *Neuron* 19: 10 531-537).

Pure recombinant chick collapsin-1 (semaphorin III) can be produced by the methods set forth in the following references (Luo, et al. (1993) *Cell* 75: 217-227.); Koppel, et al. *J. Biol. Chem.* 273: 15708-15713, Feiner, et al. (1997) *Neuron* 19: 539-545).

15 We have shown that when collapsin-1 was added to cultures of porcine endothelial cells (PAE) and PAE neuropilin-1 and/or KDR transfectants, ¹²⁵I-Collapsin was found to bind to PAE cells expressing neuropilin-1 but not to PAE cells expressing KDR. Furthermore, in a Boyden chamber assay, collapsin-1 inhibited the basal migration of PAE expressing neuropilin-1, by about 60-70%, but had no effect on parental PAE or PAE expressing KDR alone (Fig. 20). Inhibition was dose-dependent and half-maximal inhibition occurred with 50 collapsing units/ml (as measured on DRG, 1 CU = 3 ng/ml). Thus, semaphorin/collapsins inhibit the motility of non-neuronal cells as long as neuropilin-1 is expressed. X \Leftarrow endothelial

20 Antibodies that specifically bind the NP at a region that inhibits receptor function can also be used as antagonists of the invention. Antibodies may be raised against either a peptide of the receptor or the whole molecule. Such a peptide may be presented together with a carrier protein, such as an KLH, to an animal system or, if it is long enough, say 25 amino acid residues, without a carrier.

25 In accordance with yet another aspect of the present invention, there are provided isolated antibodies or antibody fragments which selectively bind the receptor. The antibody fragments include, for example, Fab, Fab', F(ab')₂ or Fv

fragments. The antibody may be a single chain antibody, a humanized antibody or a chimeric antibody.

Antibodies, or their equivalents, or other receptor antagonists may also be used in accordance with the present invention for the treatment or prophylaxis of cancers.

5 Administration of a suitable dose of the antibody or the antagonist may serve to block the receptor and this may provide a crucial time window in which to treat the malignant growth.

Prophylaxis may be appropriate even at very early stages of the disease, as it is not known what specific event actually triggers metastasis in any given case. Thus,
10 administration of the antagonists which interfere with receptor activity, may be effected as soon as cancer is diagnosed, and treatment continued for as long as is necessary, preferably until the threat of the disease has been removed. Such treatment may also be used prophylactically in individuals at high risk for development of certain cancers, e.g., prostate or breast.

15 It will be appreciated that antibodies for use in accordance with the present invention may be monoclonal or polyclonal as appropriate. Antibody equivalents of these may comprise: the Fab' fragments of the antibodies, such as Fab, Fab', F(ab')₂ and Fv; idiotopes; or the results of allotope grafting (where the recognition region of an animal antibody is grafted into the appropriate region of a human antibody to avoid
20 an immune response in the patient), for example. Single chain antibodies may also be used. Other suitable modifications and/or agents will be apparent to those skilled in the art.

Chimeric and humanized antibodies are also within the scope of the invention. It is expected that chimeric and humanized antibodies would be less immunogenic in a
25 human subject than the corresponding non-chimeric antibody. A variety of approaches for making chimeric antibodies, comprising for example a non-human variable region and a human constant region, have been described. See, for example, Morrison et al., Proc. Natl. Acad. Sci. U.S.A. 81,6851 (1985); Takeda, et al., Nature 314,452(1985), Cabilly et al., U.S. Pat. No. 4,816,567; Boss et al., U.S. Pat. No. 4,816,397; Tanaguchi
30 et al., European Patent Publication EP 171496; European Patent Publication 0173494, United Kingdom Patent GB 2177096B. Additionally, a chimeric antibody can be

further "humanized" such that parts of the variable regions, especially the conserved framework regions of the antigen-binding domain, are of human origin and only the hypervariable regions are of non-human origin. Such altered immunoglobulin molecules may be made by any of several techniques known in the art, (e.g., Teng et al., Proc. Natl. Acad. Sci. U.S.A., 80, 7308-7312 (1983); Kozbor et al., Immunology Today, 4, 7279 (1983); Olsson et al., Meth. Enzymol., 92, 3-16 (1982)), and are preferably made according to the teachings of PCT Publication WO92/06193 or EP 0239400. Humanized antibodies can be commercially produced by, for example, Scotgen Limited, 2 Holly Road, Twickenham, Middlesex, Great Britain.

10 The present invention further provides use of neuropilin for intracellular or extracellular targets to affect binding. Intracellular targeting can be accomplished through the use of intracellularly expressed antibodies referred to as intrabodies. Extracellular targeting can be accomplished through the use of receptor specific antibodies.

15 These methods can be used to inhibit metastasis in malignant cells as we have found that the presence of these receptors is positively correlated with metastasis. One can treat a range of afflictions or diseases associated with expression of the receptor by directly blocking the receptor. This can be accomplished by a range of different approaches. One preferred approach is the use of antibodies that specifically block VEGF binding to the receptor. For example, an antibody to the VEGF binding site. 20 Antibodies to these receptors can be prepared by standard means. For example, one can use single chain antibodies to target these binding sites.

The antibody can be administered by a number of methods. One preferred method is set forth by Marasco and Haseltine in PCT WO94/02610, which is 25 incorporated herein by reference. This method discloses the intracellular delivery of a gene encoding the antibody. One would preferably use a gene encoding a single chain antibody. The antibody would preferably contain a nuclear localization sequence. One preferably uses an SV40 nuclear localization signal. By this method one can intracellularly express an antibody, which can block VEGF₁₆₅R/NP-1 or NP-2 30 functioning in desired cells.

DNA encoding human VEGF₁₆₅R/NP-1 or NP-2 and recombinant human VEGF₁₆₅R/NP-1 or NP-2 may be produced according to the methods set forth in the Examples.

5 The receptors are preferably produced by recombinant methods. A wide variety of molecular and biochemical methods are available for generating and expressing the polypeptides of the present invention; see e.g. the procedures disclosed in *Molecular Cloning, A Laboratory Manual* (2nd Ed., Sambrook, Fritsch and Maniatis, Cold Spring Harbor), *Current Protocols in Molecular Biology* (Eds. Aufubel, Brent, Kingston, More, Feidman, Smith and Stuhl, Greene Publ. Assoc.,
10 Wiley-Interscience, NY, N.Y. 1992) or other procedures that are otherwise known in the art. For example, the polypeptides of the invention may be obtained by chemical synthesis, expression in bacteria such as *E. coli* and eukaryotes such as yeast, baculovirus, or mammalian cell-based expression systems, etc., depending on the size, nature and quantity of the polypeptide.

15 The term "isolated" means that the polypeptide is removed from its original environment (e.g., the native VEGF molecule). For example, a naturally-occurring polynucleotides or polypeptides present in a living animal is not isolated, but the same polynucleotides or DNA or polypeptides, separated from some or all of the coexisting materials in the natural system, is isolated. Such polynucleotides could be part of a
20 vector and/or such polynucleotides or polypeptides could be part of a composition, and still be isolated in that such vector or composition is not part of its natural environment.

Where it is desired to express the receptor or a fragment thereof, any suitable system can be used. The general nature of suitable vectors, expression vectors and
25 constructions therefor will be apparent to those skilled in the art.

Suitable expression vectors may be based on phages or plasmids, both of which are generally host-specific, although these can often be engineered for other hosts. Other suitable vectors include cosmids and retroviruses, and any other vehicles, which may or may not be specific for a given system. Control sequences, such as
30 recognition, promoter, operator, inducer, terminator and other sequences essential

and/or useful in the regulation of expression, will be readily apparent to those skilled in the art.

Correct preparation of nucleotide sequences may be confirmed, for example, by the method of Sanger et al. (*Proc. Natl. Acad. Sci. USA* 74:5463-7 (1977)).

5 A DNA fragment encoding the receptor or fragment thereof, may readily be inserted into a suitable vector. Ideally, the receiving vector has suitable restriction sites for ease of insertion, but blunt-end ligation, for example, may also be used, although this may lead to uncertainty over reading frame and direction of insertion. In such an instance, it is a matter of course to test transformants for expression, 1 in 6 of which
10 should have the correct reading frame. Suitable vectors may be selected as a matter of course by those skilled in the art according to the expression system desired.

By transforming a suitable organism or, preferably, eukaryotic cell line, such as HeLa, with the plasmid obtained, selecting the transformant with ampicillin or by other suitable means if required, and adding tryptophan or other suitable
15 promoter-inducer (such as indoleacrylic acid) if necessary, the desired polypeptide or protein may be expressed. The extent of expression may be analyzed by SDS polyacrylamide gel electrophoresis-SDS-PAGE (Lemelli, *Nature* 227:680-685 (1970)).

Suitable methods for growing and transforming cultures etc. are usefully
20 illustrated in, for example, Maniatis (*Molecular Cloning, A Laboratory Notebook*, Maniatis et al. (eds.), Cold Spring Harbor Labs, N.Y. (1989)).

Cultures useful for production of polypeptides or proteins may suitably be cultures of any living cells, and may vary from prokaryotic expression systems up to eukaryotic expression systems. One preferred prokaryotic system is that of *E. coli*,
25 owing to its ease of manipulation. However, it is also possible to use a higher system, such as a mammalian cell line, for expression of a eukaryotic protein. Currently preferred cell lines for transient expression are the HeLa and Cos cell lines. Other expression systems include the Chinese Hamster Ovary (CHO) cell line and the baculovirus system.

30 Other expression systems which may be employed include streptomycetes, for example, and yeasts, such as *Saccharomyces* spp., especially *S. cerevisiae*. Any

system may be used as desired, generally depending on what is required by the operator. Suitable systems may also be used to amplify the genetic material, but it is generally convenient to use *E. coli* for this purpose when only proliferation of the DNA is required.

5 The polypeptides and proteins may be isolated from the fermentation or cell culture and purified using any of a variety of conventional methods including: liquid chromatography such as normal or reversed phase, using HPLC, FPLC and the like; affinity chromatography (such as with inorganic ligands or monoclonal antibodies); size exclusion chromatography; immobilized metal chelate chromatography; gel
10 electrophoresis; and the like. One of skill in the art may select the most appropriate isolation and purification techniques without departing from the scope of this invention.

 The present invention also provides binding assays using VEGF₁₆₅R/NP-1 or
15 NP-2 that permit the ready screening for compounds which affect the binding of the receptor and its ligands, e.g., VEGF₁₆₅. These assays can be used to identify
compounds that modulate, preferably inhibit metastasis and/or angiogenesis.
However, it is also important to know if a compound enhances metastasis so that its use can be avoided. For example, in a direct binding assay the compound of interest can be added before or after the addition of the labeled ligand, e.g., VEGF₁₆₅, and the
20 effect of the compound on binding or cell motility or angiogenesis can be determined by comparing the degree of binding in that situation against a base line standard with that ligand, not in the presence of the compound. The assay can be adapted depending upon precisely what is being tested.

 The preferred technique for identifying molecules which bind to the neuropilin
25 receptor utilizes a receptor attached to a solid phase, such as the well of an assay plate. The binding of the candidate molecules, which are optionally labeled (e.g., radiolabeled), to the immobilized receptor can be measured. Alternatively, competition for binding of a known, labeled receptor ligand, such as I-¹²⁵ VEGF₁₆₅, can be measured. For screening for antagonists, the receptor can be exposed to a
30 receptor ligand, e.g., VEGF₁₆₅, followed by the putative antagonist, or the ligand and antagonist can be added to the receptor simultaneously, and the ability of the

antagonist to block receptor activation can be evaluated. For example, VEGF antagonist activity may also be determined by inhibition of binding of labeled VEGF₁₆₅ to VEGF₁₆₅R as disclosed in the Examples.

5 The ability of discovered antagonists to influence angiogenesis or metastasis can also be determined using a number of known *in vivo* and *in vitro* assays. Such assays are disclosed in Jain et al., *Nature Medicine* 3, 1203-1208(1997), and the examples.

Where the present invention provides for the administration of, for example, antibodies to a patient, then this may be by any suitable route. If the tumor is still
10 thought to be, or diagnosed as, localized, then an appropriate method of administration may be by injection direct to the site. Administration may also be by injection, including subcutaneous, intramuscular, intravenous and intradermal injections.

Formulations may be any that are appropriate to the route of administration, and will be apparent to those skilled in the art. The formulations may contain a
15 suitable carrier, such as saline, and may also comprise bulking agents, other medicinal preparations, adjuvants and any other suitable pharmaceutical ingredients. Catheters are one preferred mode of administration.

Neuropilin expression may also be inhibited *in vivo* by the use of antisense technology. Antisense technology can be used to control gene expression through
20 triple-helix formation or antisense DNA or RNA, both of which methods are based on binding of a polynucleotide to DNA or RNA. An antisense nucleic acid molecule which is complementary to a nucleic acid molecule encoding receptor can be designed based upon the isolated nucleic acid molecules encoding the receptor provided by the invention. An antisense nucleic acid molecule can comprise a nucleotide sequence
25 which is complementary to a coding strand of a nucleic acid, e.g. complementary to an mRNA sequence, constructed according to the rules of Watson and Crick base pairing, and can hydrogen bond to the coding strand of the nucleic acid. The antisense sequence complementary to a sequence of an mRNA can be complementary to a sequence in the coding region of the mRNA or can be complementary to a 5' or 3'
30 untranslated region of the mRNA. Furthermore, an antisense nucleic acid can be complementary in sequence to a regulatory region of the gene encoding the mRNA,

for instance a transcription initiation sequence or regulatory element. Preferably, an antisense nucleic acid complementary to a region preceding or spanning the initiation codon or in the 3' untranslated region of an mRNA is used. An antisense nucleic acid can be designed based upon the nucleotide sequence shown in SEQ ID NO:1

5 (VEGF₁₆₅R/NP-1) or SEQ ID NO:3 (NP-2). A nucleic acid is designed which has a sequence complementary to a sequence of the coding or untranslated region of the shown nucleic acid. Alternatively, an antisense nucleic acid can be designed based upon sequences of a VEGF₁₆₅R gene, which can be identified by screening a genomic DNA library with an isolated nucleic acid of the invention. For example, the sequence
10 of an important regulatory element can be determined by standard techniques and a sequence which is antisense to the regulatory element can be designed.

The antisense nucleic acids and oligonucleotides of the invention can be constructed using chemical synthesis and enzymatic ligation reactions using procedures known in the art. The antisense nucleic acid or oligonucleotide can be
15 chemically synthesized using naturally occurring nucleotides or variously modified nucleotides designed to increase the biological stability of the molecules or to increase the physical stability of the duplex formed between the antisense and sense nucleic acids e.g. phosphorothioate derivatives and acridine substituted nucleotides can be used. Alternatively, the antisense nucleic acids and oligonucleotides can be produced
20 biologically using an expression vector into which a nucleic acid has been subcloned in an antisense orientation (i.e. nucleic acid transcribed from the inserted nucleic acid will be of an antisense orientation to a target nucleic acid of interest). The antisense expression vector is introduced into cells in the form of a recombinant plasmid, phagemid or attenuated virus in which antisense nucleic acids are produced under the
25 control of a high efficiency regulatory region, the activity of which can be determined by the cell type into which the vector is introduced. For a discussion of the regulation of gene expression using antisense genes see Weintraub, H. et al., Antisense RNA as a molecular tool for genetic analysis, Reviews - Trends in Genetics, Vol. 1 (1)1986.

The term "pharmaceutically acceptable" refers to compounds and compositions
30 which may be administered to mammals without undue toxicity. Exemplary pharmaceutically acceptable salts include mineral acid salts such as hydrochlorides,

hydrobromides, phosphates, sulfates, and the like; and the salts of organic acids such as acetates, propionates, malonates, benzoates, and the like.

The antagonists of the invention are administered orally, topically, or by parenteral means, including subcutaneous and intramuscular injection, implantation of
5 sustained release depots, intravenous injection, intranasal administration, and the like. Accordingly, antagonists of the invention may be administered as a pharmaceutical composition comprising the antibody or nucleic acid of the invention in combination with a pharmaceutically acceptable carrier. Such compositions may be aqueous solutions, emulsions, creams, ointments, suspensions, gels, liposomal suspensions, and
10 the like. Suitable carriers (excipients) include water, saline, Ringer's solution, dextrose solution, and solutions of ethanol, glucose, sucrose, dextran, mannose, mannitol, sorbitol, polyethylene glycol (PEG), phosphate, acetate, gelatin, collagen, Carbopol Registered TM, vegetable oils, and the like. One may additionally include suitable preservatives, stabilizers, antioxidants, antimicrobials, and buffering agents, for
15 example, BHA, BHT, citric acid, ascorbic acid, tetracycline, and the like. Cream or ointment bases useful in formulation include lanolin, Silvadene Registered TM (Marion), Aquaphor Registered TM (Duke Laboratories), and the like. Other topical formulations include aerosols, bandages, and other wound dressings. Alternatively one may incorporate or encapsulate the compounds such as an antagonist in a suitable
20 polymer matrix or membrane, thus providing a sustained-release delivery device suitable for implantation near the site to be treated locally. Other devices include indwelling catheters and devices such as the Alzet Registered TM minipump. Ophthalmic preparations may be formulated using commercially available vehicles such as Sorbi-care Registered TM (Allergan), Neodecadron Registered TM (Merck,
25 Sharp & Dohme), Lacrilube Registered TM, and the like, or may employ topical preparations such as that described in U.S. Pat. No. 5,124,155, incorporated herein by reference. Further, one may provide an antagonist in solid form, especially as a lyophilized powder. Lyophilized formulations typically contain stabilizing and bulking agents, for example human serum albumin, sucrose, mannitol, and the like. A
30 thorough discussion of pharmaceutically acceptable excipients is available in Remington's Pharmaceutical Sciences (Mack Pub. Co.).

The NP antagonists of the invention can be combined with a therapeutically effective amount of another molecule which negatively regulates angiogenesis which may be, but is not limited to, TNP-470, platelet factor 4, thrombospondin-1, tissue inhibitors of metalloproteases (TIMP1 and TIMP2), prolactin (16-Kd fragment),
5 angiostatin (38-Kd fragment of plasminogen), endostatin, bFGF soluble receptor, transforming growth factor beta, interferon alfa, soluble KDR and FLT-1 receptors and placental proliferin-related protein.

An NP antagonist of the invention may also be combined with chemotherapeutic agents.

10 The DNA encoding an antagonist, e.g., a collapsin, can be used in the form of gene therapy and delivered to a host by any method known to those of skill in the art to treat disorders associated with VEGF.

The amount of an NP antagonist required to treat any particular disorder will of course vary depending upon the nature and severity of the disorder, the age and
15 condition of the subject, and other factors readily determined by one of ordinary skill in the art.

All references cited above or below are herein incorporated by reference.

The present invention is further illustrated by the following Examples. These Examples are provided to aid in the understanding of the invention and are not
20 construed as a limitation thereof.

EXAMPLE 1

Experimental procedures Materials

25

Cell culture media, lipofectin and lipofectamin reagents for transfection were purchased from Life Technologies. Human recombinant VEGF₁₆₅ and VEGF₁₂₁ were produced in Sf-21 insect cells infected with recombinant baculovirus vectors encoding either human VEGF₁₆₅ or VEGF₁₂₁ as previously described (Cohen et al., *Growth*
30 *Factors*, 7, 131-138 (1992); Cohen et al., *J. Biol. Chem.*, 270, 11322-11326 (1995)). GST VEGF exons 7+8 fusion protein was prepared in E.Coli and purified as previously described (Soker et al., *J. Biol. Chem.*, 271, 5761-5767 (1996)). Heparin,

hygromycin B and protease inhibitors were purchased from Sigma (St. Louis, MO). ^{125}I -Sodium, ^{32}P -dCTP, and GeneScreen-Plus hybridization transfer membrane were purchased from DuPont NEN (Boston, MA). Disuccinimidyl suberate (DSS) and IODO-BEADS were purchased from Pierce Chemical Co. (Rockford, IL). Con A
5 Sepharose was purchased from Pharmacia LKB Biotechnology Inc. (Piscataway, NJ). RNAzol-B was purchased from TEL-TEST Inc. (Friendswood, TX). Silver Stain kit and Trans-Blot PVDF membranes were purchased from Bio-Rad Laboratories (Hercules, CA). Multiple tissue northern blot membranes were purchased from Clontech (Palo Alto, CA). PolyAtract mRNA isolation kits were purchased from
10 Promega (Madison, WI). RediPrime DNA labeling kits and molecular weight markers were purchased from Amersham (Arlington Heights, IL). Plasmids: pcDNA3.1 was purchased from Invitrogen (Carlsbad, CA), and pCPhygro, containing the CMV promoter and encoding hygromycin B phosphorylase, was kindly provided by Dr. Urban Deutsch (Max Plank Institute, Bad Nauheim, Germany). Restriction
15 endonucleases and Ligase were purchased from New England Biolabs, Inc (Beverly, MA). NT-B2 photographic emulsion and x-ray film were purchased from the Eastman Kodak company (Rochester NY).

Cell culture

20 Human umbilical vein EC (HUVEC) were obtained from American Type Culture Collection (ATCC) (Rockville, MD), and grown on gelatin coated dishes in M-199 medium containing 20% fetal calf serum (FCS) and a mixture of glutamine, penicillin and streptomycin (GPS). Basic FGF (2 ng/ml) was added to the culture medium every other day. Parental porcine aortic endothelial (PAE) cells and PAE cells
25 expressing KDR (PAE/KDR) (Waltenberger et al., *J. Biol. Chem.* 269, 26988-26995 (1994)) were kindly provided by Dr. Lena Claesson-Welsh and were grown in F12 medium containing 10% FCS and GPS. MDA-MB-231 cells and MDA-MB-453 cells were obtained from ATCC, and grown in DMEM containing 10% FCS and GPS. The human melanoma cell lines, RU-mel, EP-mel and WK-mel were kindly provided by
30 Dr. Randolph Byer (Boston University Medical School, Boston, MA), and grown in DMEM containing 2% FCS, 8% calf serum and GPS. Human metastatic prostate

adenocarcinoma, LNCaP and prostate carcinoma, PC3 cells were kindly provided by Dr. Michael Freeman (Children's Hospital, Boston, MA), and grown in RPMI 1640 containing 5% FCS and GPS.

5 Purification and protein sequencing

Approximately 5×10^8 MDA-MB-231 cells grown in 150 cm dishes were washed with PBS containing 5 mM EDTA, scraped and centrifuged for 5 min at 500g. The cell pellet was lysed with 150 ml of 20 mM HEPES, pH 8.0, 0.5% triton X-100 and protease inhibitors including 1 mM AEBSF, 5 μ g/ml leupeptin and 5 μ g/ml aprotinin for 30 min on ice, and the lysate was centrifuged at 30,000 x g for 30 min. $MnCl_2$ and $CaCl_2$ were added to the supernatant to obtain a final concentration of 1mM each. The lysate was absorbed onto a Con A Sepharose column (7 ml) and bound proteins were eluted with 15 ml 20 mM HEPES, pH 8.0, 0.2 M NaCl, 0.1% triton X-100 and 1 M methyl- α -D-mannopyranoside at 0.2 ml/min. The elution was repeated twice more at 30 minute intervals. The Con A column eluates were pooled and incubated for 12 h at 4°C with 0.5 ml of VEGF₁₆₅- Sepharose beads, containing about 150 μ g VEGF₁₆₅, prepared as described previously (Wilchek and Miron, *Biochem. Int.* 4, 629-635. (1982)). The VEGF₁₆₅-Sepharose beads were washed with 50 ml of 20 mM HEPES, pH 8.0, 0.2 M NaCl and 0.1% triton X-100 and then with 25 ml of 20 mM HEPES, pH 8.0. The beads were boiled in SDS-PAGE buffer and bound proteins were separated by 6% SDS-PAGE. Proteins were transferred to a TransBlot PVDF membrane using a semi-dry electric blotter (Hoeffer Scientific), and the PVDF membrane was stained with 0.1% Coomassie Brilliant Blue in 40% methanol. The two prominent proteins in a 130-140 kDa doublet were cut out separately and N-terminally sequenced using an Applied Biosystems model 477A microsequenator as a service provided by Dr. William Lane of the Harvard Microchemistry facility (Cambridge, MA).

Expression cloning and DNA sequencing

Complementary DNA (cDNA) was synthesized from 5 μ g 231 mRNA. Double-stranded cDNA was ligated to *EcoRI* adaptors, and size-fractionated on a 5-20% potassium acetate gradient. DNA fragments larger than 2kb were ligated to an eukaryotic expression plasmid, pcDNA3.1. The plasmid library was transfected into

E.coli to yield a primary library of approximately 1×10^7 individual clones. A portion of the transformed bacteria was divided into 240 pools, each representing approximately 3×10^3 individual clones. DNA prepared from each pool was used to transfect COS-7 cells seeded in 12 well dishes, using the Lipofectin reagent according to the manufacturer's instructions. Three days after transfection, the cells were incubated on ice for 2 h with ^{125}I -VEGF₁₆₅ (10 ng/ml) in the presence of 1 $\mu\text{g/ml}$ heparin, washed and fixed with 4% paraformaldehyde in PBS. ^{125}I -VEGF₁₆₅ binding to individual cells was detected by overlaying the monolayers with photographic emulsion, NT-B2, and developing the emulsion after two days as described (Gearing et al., 1989). Seven positive DNA pools were identified and DNA from one of the positive pools was used to transform E.Coli. The E. coli were sub-divided into 50 separate pools and plated onto 50 LB ampicillin dishes, with each pool representing approximately 100 clones. DNA made from these pools was transfected into COS-7 cells which were screened for ^{125}I -VEGF₁₆₅ binding as described above. Twenty positive pools were detected at this step, and their corresponding DNAs were used to transform *E. Coli*. Each pool was plated onto separate LB ampicillin dishes and DNA was prepared from 96 individual colonies and screened in a 96-well two dimensional grid for ^{125}I -VEGF₁₆₅ binding to transfected COS-7 cells as described above. Seven single clones were identified as being positive at this step. The seven positive plasmid clones were amplified and their DNA was analyzed by restriction enzyme digestion. Six clones showed an identical digestion pattern of digest and one was different. One clone from each group was submitted for automated DNA sequencing.

Northern Analysis

Total RNA was prepared from cells in culture using RNAzol according to the manufacturer's instructions. Samples of 20 μg RNA were separated on a 1% formaldehyde-agarose gel, and transferred to a GeneScreen-Plus membrane. The membrane was hybridized with a ^{32}P labeled fragment of human VEGF₁₆₅R/NP-1 cDNA, corresponding to nucleotides 63-454 in the ORF, at 63°C for 18 h. The membrane was washed and exposed to an x-ray film for 18 h. A commercially-obtained multiple human adult tissue mRNA blot (Clontech, 2 $\mu\text{g/lane}$) was probed

for human NP-1 in a similar manner. The multiple tissue blot was stripped by boiling in the presence of 0.5% SDS and re-probed with a ^{32}P labeled fragment of KDR cDNA corresponding to nucleotides 2841-3251 of the ORF (Terman et al., *Oncogene* 6, 1677-1683 (1991)).

5

Transfection of PAE cells

Parental PAE cells and PAE cells expressing KDR (PAE/KDR) (Waltenberger et al., 1994) were obtained from Dr. Lena Claesson-Welsh. Human NP-1 cDNA was digested with *Xho*I and *Xba*I restriction enzymes and subcloned into the
10 corresponding sites of pCPhygro, to yield pCPhyg-NP-1. PAE and PAE/KDR cells were grown in 6 cm dishes and transfected with 5 μg of pCPhyg-NP-1 using Lipofectamine, according to the manufacturer's instructions. Cells were allowed to grow for an additional 48 h and the medium was replaced with fresh medium containing 200 $\mu\text{g}/\text{ml}$ hygromycin B. After 2 weeks, isolated colonies (5-10 $\times 10^3$
15 cell/colony) were transferred to separate wells of a 48 well dish and grown in the presence of 200 $\mu\text{g}/\text{ml}$ hygromycin B. Stable PAE cell clones expressing VEGF₁₆₅R/NP-1 (PAE/NP-1) or co-expressing VEGF₁₆₅R/NP-1 and KDR (PAE/KDR/NP-1) were screened for VEGF₁₆₅ receptor expression by binding and cross linking of ^{125}I -VEGF₁₆₅. For transient transfection, PAE/KDR cells were
20 transfected with VEGF₁₆₅R/NP-1 as described above and after three days ^{125}I -VEGF₁₆₅ cross-linking analysis was carried out.

Radio-iodination of VEGF, binding and cross-linking experiments.

The radio-iodination of VEGF₁₆₅ and VEGF₁₂₁ using IODO-BEADS was
25 carried out as previously described (Soker et al., *J. Biol. Chem.* 272, 31582-31588 (1997)). The specific activity ranged from 40,000-100,000 cpm/ng protein. Binding and cross-linking experiments using ^{125}I -VEGF₁₆₅ and ^{125}I -VEGF₁₂₁ were performed as previously described (Gitay-Goren et al., *J. Biol. Chem.* 267, 6093-6098 (1992); Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)). VEGF binding was quantitated by
30 measuring the cell-associated radioactivity in a γ -counter (Beckman, Gamma 5500). The counts represent the average of three wells. All experiments were repeated at least

three times and similar results were obtained. The results of the binding experiments were analyzed by the method of Scatchard using the LIGAND program (Munson and Rodbard, 1980). ^{125}I -VEGF₁₆₅ and ^{125}I -VEGF₁₂₁ cross linked complexes were resolved by 6% SDS/PAGE and the gels were exposed to an X-Ray film. X-ray films were
5 subsequently scanned by using an IS-1000 digital imaging system (Alpha Innotech Corporation)

Purification of VEGF₁₆₅R

Cross-linking of ¹²⁵I-VEGF₁₆₅ to cell surface receptors of 231 cells results in formation of a 165-175 kDa labeled complex (Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)). These cells have about 1-2 x 10⁵ VEGF₁₆₅ binding sites/cell. In contrast to VEGF₁₆₅, VEGF₁₂₁ does not bind to the 231 cells and does not form a ligand-receptor complex (Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)). The relatively high VEGF₁₆₅R number and the lack of any detectable KDR or Flt-1 mRNA in 231 cells (not shown) suggested that these cells would be a useful source for VEGF₁₆₅R purification. Preliminary characterization indicated that VEGF₁₆₅R is a glycoprotein and accordingly, a 231 cell lysate prepared from approximately 5 x 10⁸ cells was absorbed onto a Con A Sepharose column. Bound proteins, eluted from the Con A column, were incubated with VEGF₁₆₅-Sepharose and the VEGF₁₆₅- affinity purified proteins were analyzed by SDS-PAGE and silver staining (Figure 9, lane 2). A prominent doublet with a molecular mass of about 130-135 kDa was detected. This size is consistent with the formation of a 165-175 kDa complex of 40-45 kDa VEGF₁₆₅ bound to receptors approximately 130-135 kDa in size (Figure 9, lane 1). The two bands were excised separately and N-terminal amino acid sequencing was carried out (Figure 1, right). Both the upper and lower bands had similar N-terminal amino acid sequences which showed high degrees of sequence homology to the predicted amino acid sequences in the N-terminal regions of mouse (Kawakami et al., *J. Neurobiol.* 29, 1-17 (1995)) and human neuropilin-1 (NP-1) (He and Tessier-Lavigne, *Cell* 90739-751 (1997)).

Expression cloning of VEGF₁₆₅R from 231 cell-derived mRNA

Concomitant with the purification, VEGF₁₆₅R was cloned by expression cloning (Aruffo and Seed, *Proc. Natl. Acad. Sci. USA* 84, 8573-8577 (1987a); Aruffo and Seed, *EMBO J.*, 6, 3313-3316 (1987b); Gearing et al., *EMBO J.* 8, 3667-3676 (1989)). For expression cloning, 231 cell mRNA was used to prepare a cDNA library of approximately 10⁷ clones in a eukaryotic expression plasmid. *E. coli* transformed with the plasmid library were divided into pools. The DNA prepared from each pool were transfected into COS-7 cells in separate wells and individual cells were screened

for the ability to bind ^{125}I -VEGF₁₆₅ as detected by autoradiography of monolayers overlaid with photographic emulsion (Fig 2A). After three rounds of subpooling and screening, seven single positive cDNA clones were obtained. Figure 2B shows binding of ^{125}I -VEGF₁₆₅ to COS-7 cells transfected with one of these single positive clones

5 (clone A2).

Restriction enzyme analysis revealed that six of the seven positive single clones had identical restriction digestion patterns but that one clone had a pattern that was different (not shown). Sequencing of one of these similar cDNA clones, clone A2 (Figure 3), showed it to be identical to a sequence derived from a human-expressed
10 sequence tag data bank (dbEST). This sequence also showed a high percentage of homology to the sequence of mouse neuropilin, NP-1 (Kawakami et al., *J. Neurobiol* 29, 1-17 (1995)). After we had cloned human VEGF₁₆₅R, two groups reported the cloning of rat and human receptors for semaphorin III and identified them to be NP-1 (He and Tessier-Lavigne, *Cell* 90, 739-751 (1997); Kolodkin et al., *Cell* 90, 753-762
15 (1997)). The 231 cell-derived VEGF₁₆₅R cDNA sequence is virtually identical (see figure legend 3 for exceptions) to the human NP-1 sequence (He and Tessier-Lavigne, *Cell* 90, 739-751 (1997)). Significantly, the predicted amino acid sequence obtained by expression cloning (Figure 3) confirmed the identification of VEGF₁₆₅R as NP-1 that was determined by N-terminal sequencing (Figure 1), and we have therefore
20 named this VEGF receptor, VEGF₁₆₅R/NP-1.

The human VEGF₁₆₅R/NP-1 cDNA sequence predicts an open reading frame (ORF) of 923 amino acids with two hydrophobic regions representing putative signal peptide and transmembrane domains (Figure 3). Overall, the sequence predicts ectodomain, transmembrane and cytoplasmic domains consistent with the structure of
25 a cell surface receptor. The N-terminal sequence obtained via protein purification as shown in Figure 1 is downstream of a 21 amino acid putative hydrophobic signal peptide domain, thereby indicating directly where the signal peptide domain is cleaved and removed. The short cytoplasmic tail of 40 amino acids is consistent with results demonstrating that soluble VEGF₁₆₅R/NP-1 released by partial trypsin digestion of
30 231 cells is similar in size to intact VEGF₁₆₅R/NP-1 (not shown).

Sequence analysis of the one clone obtained by expression cloning that had a different restriction enzyme profile predicted an open reading frame of 931 amino acids with about a 47% homology to VEGF₁₆₅R/NP-1 (Figure 4). This human cDNA has a 93% sequence homology with rat neuropilin-2 (NP-2) and is identical to the recently cloned human NP-2 (Chen et al., *Neuron*, 19, 547-559 (1997)).

Expression of VEGF₁₆₅R/NP-1 in adult cell lines and tissues

Reports of NP-1 gene expression have been limited so far to the nervous system of the developing embryo (Takagi et al., *Dev. Biol.* 122, 90-100 (1987); Kawakami et al., *J. Neurobiol.* 29, 1-17 (1995); Takagi et al., *Dev. Biol.* 170, 207-222 (1995)). Cell surface VEGF₁₆₅R/NP-1, however, is associated with non-neuronal adult cell types such as EC and a variety of tumor-derived cells (Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)). Northern blot analysis was carried out to determine whether cells that crossed-linked ¹²⁵I-VEGF₁₆₅ also synthesized VEGF₁₆₅R/NP-1 mRNA. (Figure 5). VEGF₁₆₅R/NP-1 mRNA levels were highest in 231 and PC3 cells. VEGF₁₆₅R/NP-1 mRNA was detected to a lesser degree in HUVEC, LNCaP, EP-mel and RU-mel cells. There was little if any expression in MDA-MB-453 and WK-mel cells. The VEGF₁₆₅R/NP-1 gene expression patterns were consistent with our previous results showing that HUVEC, 231, PC3, LNCaP, EP-mel and RU-mel cells bind ¹²⁵I-VEGF₁₆₅ to cell surface VEGF₁₆₅R/NP-1 but that MDA-MB-453 and WK-mel cells do not (Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)).

VEGF₁₆₅R/NP-1 gene expression was analyzed also by Northern blot in a variety of adult tissues in comparison to KDR gene expression (Figure 6). VEGF₁₆₅R/NP-1 mRNA levels were relatively highly in adult heart and placenta and relatively moderate in lung, liver, skeletal muscle, kidney and pancreas. A relatively low level of VEGF₁₆₅R/NP-1 mRNA was detected in adult brain. Interestingly, previous analysis of NP-1 gene expression in mouse and chicken brain suggested that this gene was expressed primarily during embryonic development and was greatly diminished after birth (Kawakami et al., *J. Neurobiol.* 29, 1-17 (1995); Takagi et al., *Dev. Biol.* 170, 207-222 (1995)). The tissue distribution of KDR mRNA was similar to that of VEGF₁₆₅R/NP-1 with the exception that it was not expressed highly in the

heart. These results indicate that VEGF₁₆₅R/NP-1 is expressed widely in adult non-neuronal tissue, including tissues in which angiogenesis occurs such as heart and placenta.

5 Characterization of VEGF₁₆₅ binding to VEGF₁₆₅R/NP-1

In order to characterize the binding properties of VEGF₁₆₅R/NP-1, porcine aortic endothelial (PAE) cells were transfected with the cDNA of VEGF₁₆₅R/NP-1. The PAE cells were chosen for these expression studies because they express neither KDR, Flt-1 (Waltenberger et al., *J. Biol. Chem.* 269, 26988-26995 (1994)) nor VEGF₁₆₅R. Stable cell lines synthesizing VEGF₁₆₅R/NP-1 (PAE/NP-1) were established and ¹²⁵I-VEGF₁₆₅ binding experiments were carried out (Fig 7). ¹²⁵I-VEGF₁₆₅ binding to PAE/NP-1 cells increased in a dose-dependent manner and reached saturation at approximately 30 ng/ml demonstrating that VEGF₁₆₅R/NP-1 is a specific VEGF₁₆₅ receptor (Figure 7A). Scatchard analysis of VEGF₁₆₅ binding revealed a single class of VEGF₁₆₅ binding sites with a K_d of approximately 3.2 x 10⁻¹⁰ M and approximately 3 x 10⁵ ¹²⁵I-VEGF₁₆₅ binding sites per cell (Figure 7B). Similar K_d values were obtained for several independently-generated PAE/NP-1 clones, although the receptor number varied from clone to clone (not shown). The K_d of 3 x 10⁻¹⁰ M for the PAE/NP-1 cell lines is consistent with the 2-2.8 x 10⁻¹⁰ M K_d values obtained for VEGF₁₆₅R/NP-1 expressed naturally by HUVEC and 231 cells (Gitay-Goren et al., *J. Biol. Chem.* 267, 6093-6098 (1992); Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)). The binding of ¹²⁵I-VEGF₁₆₅ to PAE/NP-1 cells was enhanced by 1 µg/ml heparin (not shown), consistent with previous studies showing that heparin enhances ¹²⁵I-VEGF₁₆₅ binding to VEGF₁₆₅R/NP-1 on HUVEC and 231 cells (Gitay-Goren et al., *J. Biol. Chem.* 267, 6093-6098 (1992); Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)).

Isoform-specific binding of VEGF to cells expressing VEGF₁₆₅R/NP-1

VEGF₁₆₅, but not VEGF₁₂₁, binds to VEGF₁₆₅R/NP-1 on HUVEC and 231 cells (Gitay-Goren et al., *J. Biol. Chem.* 271, 5519-5523 (1992); Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)). To ascertain whether cells transfected with

VEGF₁₆₅R/NP-1 had the same binding specificity, PAE/NP-1 cells were incubated with ¹²⁵I-VEGF₁₆₅ or ¹²⁵I-VEGF₁₂₁ followed by cross-linking (Figure 8). ¹²⁵I-VEGF₁₆₅ did not bind to parental PAE cells (Figure 8, lane 3) but did bind to PAE/NP-1 cells via VEGF₁₆₅R/NP-1 (Figure 8, lane 4). The radiolabeled complexes formed with VEGF₁₆₅R/NP-1 were similar in size to those formed in HUVEC (Figure 8, lane 1) and PC3 cells (Figure 8, lane 2). On the other hand, ¹²⁵I-VEGF₁₂₁ did not bind to either parental PAE (Figure 8, lane 7) or to PAE/NP-1 cells (Figure 8, lane 8). These results demonstrate that the VEGF isoform-specific binding that occurs with cells expressing endogenous VEGF₁₆₅R/NP-1 such as HUVEC, 231 and PC3 cells, can be replicated in cells transfected with VEGF₁₆₅R/NP-1 cDNA and support the finding that VEGF₁₆₅R and NP-1 are identical.

Co-expression of VEGF₁₆₅R/NP-1 and KDR modulates VEGF₁₆₅ binding to KDR

To determine whether expression of VEGF₁₆₅R/NP-1 had any effect on VEGF₁₆₅ interactions with KDR, PAE cells that were previously transfected with KDR cDNA to produce stable clones of PAE/KDR cells (Waltenberger et al., *J. Biol. Chem.* 269, 26988-26995 (1994)), were transfected with VEGF₁₆₅R/NP-1 cDNA and stable clones expressing both receptors (PAE/KDR/NP-1) were obtained. These cells bound ¹²⁵I-VEGF₁₆₅ to KDR (Figure 8, lane 6, upper complex) and to VEGF₁₆₅R/NP-1 (Figure 8, lane 6, lower complex) to yield a cross-linking profile similar to HUVEC (Figure 8, lane 1). On the other hand, the PAE/KDR/NP-1 cells bound ¹²⁵I-VEGF₁₂₁ to form a complex only with KDR (Figure 8, lanes 9 and 10), consistent with the inability of VEGF₁₂₁ to bind VEGF₁₆₅R/NP-1.

It appeared that in cells co-expressing KDR and VEGF₁₆₅R/NP-1 (Figure 8, lane 6), the degree of ¹²⁵I-VEGF₁₆₅-KDR 240 kDa complex formation was enhanced compared to the parental PAE/KDR cells (Figure 8, lane 5). These results were reproducible and the degree of ¹²⁵I-VEGF₁₆₅-KDR 240 kDa complex formation in different clones was correlated positively with the levels of VEGF₁₆₅R/NP-1 expressed (not shown). However, it could not be ruled out definitively that these differential KDR binding results were possibly due to clonal selection post-transfection.

Therefore, parental PAE/KDR cells were transfected with VEGF₁₆₅R/NP-1 cDNA and ¹²⁵I-VEGF₁₆₅ was bound and cross-linked to the cells three days later in order to avoid any diversity of KDR expression among individual clones (Figure 9). A labeled 240 kDa complex containing KDR was formed in parental PAE/KDR cells (Fig 9, lane 1) and in PAE/KDR cells transfected with the expression vector (Figure 9, lane 2). However, when ¹²⁵I-VEGF₁₆₅ was cross-linked to PAE/KDR cells transiently expressing VEGF₁₆₅R/NP-1, a more intensely labeled 240 kDa complex, about 4 times greater, was observed (Figure 9, lane 3), compared to parental PAE/KDR cells (Figure 9, lane 1) and PAE/KDR cells transfected with expression vector (Figure 9, lane 2). These results suggest that co-expression of KDR and VEGF₁₆₅R/NP-1 genes in the same cell enhances the ability of VEGF₁₆₅ to bind to KDR.

A GST-VEGF Exon 7+8 fusion protein inhibits VEGF₁₆₅ binding to VEGF₁₆₅R/NP-1 and KDR

We have shown that ¹²⁵I-VEGF₁₆₅ binds to VEGF₁₆₅R/NP-1 through its exon 7-encoded domain (Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)). In addition, a GST fusion protein containing the peptide encoded by VEGF exon 7+8 (GST-Ex 7+8), inhibits completely the binding of ¹²⁵I-VEGF₁₆₅ to VEGF₁₆₅R/NP-1 associated with 231 cells and HUVEC (Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996); Soker et al., *J. Biol. Chem.* 272, 31582-31588 (1997)). When, added to PAE/NP-1 cells, the fusion protein completely inhibited binding to VEGF₁₆₅R/NP-1 (Figure 10, lane 2 compared to lane 1). On the other hand, it did not inhibit ¹²⁵I-VEGF₁₆₅ binding at all to KDR (Figure 10, lane 4 compared to lane 3). Thus, these results demonstrate that GST-Ex 7+8 binds directly to VEGF₁₆₅R/NP-1 but does not bind to KDR. The effects of GST-Ex 7+8 are different, however, in cells co-expressing both VEGF₁₆₅R/NP-1 and KDR (PAE/KDR/NP-1). Consistent with the results in Figures 8 and 9, the degree of ¹²⁵I-VEGF₁₆₅ binding to KDR in PAE/KDR/NP-1 cells (Figure 10, lane 5) was greater than to the parental PAE/KDR cells (Figure 10, lane 3). Interestingly, in PAE/KDR/NP-1 cells, GST-Ex 7+8 inhibited not only ¹²⁵I-VEGF₁₆₅ binding to VEGF₁₆₅R/NP-1 completely as expected, but it also inhibited binding to KDR substantially which was unexpected (Figure 10, lane 6 compared to lane 5). In the

presence of GST-Ex 7+8, binding of ^{125}I -VEGF₁₆₅ to KDR in these cells was reduced to the levels seen in parental PAE/KDR cells not expressing VEGF₁₆₅R/NP-1 (Figure 10, lane 6 compared to lanes 3 and 4). Since the fusion protein does not bind directly to KDR, these results suggest that inhibiting the binding of ^{125}I -VEGF₁₆₅ to VEGF₁₆₅R/NP-1 directly, inhibits its binding to KDR indirectly. Taken together, the results in Figures 8, 9 and 10 suggest that interactions of VEGF₁₆₅ with VEGF₁₆₅R/NP-1 enhance VEGF interactions with KDR.

Neuropilin-1 is an isoform-specific VEGF₁₆₅ receptor

10 Recently, we described a novel 130-135 kDa VEGF cell surface receptor that binds VEGF₁₆₅ but not VEGF₁₂₁ and that we named, accordingly, VEGF₁₆₅R (Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)). We have now purified VEGF₁₆₅R, expression cloned its cDNA, and shown it to be identical to human neuropilin-1 (NP-1) (He and Tessier-Lavigne, *Cell* 90 739-751 (1997)). The evidence that VEGF₁₆₅R is
15 identical to NP-1 and that NP-1 serves as a receptor for VEGF₁₆₅ is as follows: i) purification of VEGF₁₆₅R protein from human MDA-MB-231 (231) cells using VEGF affinity, yielded a 130-140 kDa doublet upon SDS-PAGE and silver stain. N-terminal sequencing of both proteins yielded the same N-terminal sequence of 18 amino acids that demonstrated a high degree of homology to mouse NP-1 (Kawakami et al., *J. Neurobiol.* 29, 1-17 (1995)); ii) After we purified VEGF₁₆₅R from human 231 cells, the cloning of human NP-1 was reported (He and Tessier-Lavigne, *Cell* 90, 739-751 (1997)) and the N-terminal sequence of human VEGF₁₆₅R was found to be identical to a sequence in the N-terminal region of human NP-1; iii) Expression cloning using a
25 231 cell cDNA library resulted in isolation of several cDNA clones and their sequences were identical to the human NP-1 cDNA sequence (He and Tessier-Lavigne, *Cell* 90, 739-751 (1997)). The combination of purification and expression cloning has the advantage over previous studies where only expression cloning was used (He and Tessier-Lavigne, *Cell* 90, 739-751 (1997); Kolodkin et al., *Cell* 90, 753-762 (1997)), in allowing unambiguous identification of the NP-1 protein N-terminus;
30 iv) Northern blot analysis of NP-1 gene expression was consistent with previous ^{125}I -VEGF₁₆₅ cross-linking experiments (Soker et al., *J. Biol. Chem.* 271, 5761-5767

(1996)). Cells that bound VEGF₁₆₅ to VEGF₁₆₅R synthesized relatively abundant NP-1 mRNA while cells that showed very little if any VEGF₁₆₅ binding, did not synthesize much if any NP-1 mRNA; v) when NP-1 was expressed in PAE cells, the transfected, but not the parental cells, were able to bind VEGF₁₆₅ but not VEGF₁₂₁, consistent with the isoform specificity of binding previously shown for HUVEC and 231 cells (Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)). Furthermore, the K_d of ¹²⁵I-VEGF₁₆₅ binding of to PAE expressing NP-1 was about 3 x 10⁻¹⁰ M, consistent with previous K_d binding values of 2-2.8 x 10⁻¹⁰ M for 231 cells and HUVEC (Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)); and vi) The binding of VEGF₁₆₅ to cells expressing NP-1 post-transfection was more efficient in the presence of heparin as was the binding of this ligand to HUVEC and 231 cells (Gitay-Goren et al., *J. Biol. Chem.* 267, 6093-6098 (1992); Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)). Taken together, these results show not only that VEGF₁₆₅R is identical to NP-1 but that it is a functional receptor that binds VEGF₁₆₅ in an isoform-specific manner. Accordingly, we have named this VEGF receptor VEGF₁₆₅R/NP-1.

In addition to the expression cloning of VEGF₁₆₅R/NP-1 cDNA, another human cDNA clone was isolated whose predicted amino acid sequence was 47% homologous to that of VEGF₁₆₅R/NP-1 and over 90% homologous to rat neuropilin-2 (NP-2) which was recently cloned (Kolodkin et al., *Cell* 90, 753-762 (1997)). NP-2 binds members of the collapsin/semaphorin family selectively (Chen et al., *Neuron* 19, 547-559 (1997)).

The discovery that NP-1 serves as a receptor for VEGF₁₆₅ was a surprise since NP-1 had previously been shown to be associated solely with the nervous system during embryonic development (Kawakami et al., *J. Neurobiol.* 29, 1-17 (1995); Takagi et al., *Dev. Biol.* 170, 207-222 (1995)) and more recently as a receptor for members of the collapsin/semaphorin family (He and Tessier-Lavigne, *Cell* 90, 739-751 (1997); Kolodkin et al., *Cell* 90, 753-762 (1997)). NP-1 is a 130-140 kDa transmembrane glycoprotein first identified in the developing *Xenopus* optic system (Takagi et al., *Dev. Biol.* 122, 90-100 (1987); Takagi et al., *Neuron* 7, 295-307 (1991)). NP-1 expression in the nervous system is highly regulated spatially and temporally during development and in particular is associated with those

developmental stages when axons are actively growing to form neuronal connections.(Fujisawa et al., *Dev. Neurosci.* 17, 343-349 (1995); Kawakami et al., *J. Neurobiol* 29, 1-17 (1995); Takagi et al., *Dev. Biol.* 170, 207-222 (1995)). The NP-1 protein is associated with neuronal axons but not the stomata (Kawakami et al., *J.*

5 *Neurobiol* 29, 1-17 (1995)). Functionally, neuropilin has been shown to promote neurite outgrowth of optic nerve fibers in vitro (Hirata et al., *Neurosci. Res.* 17, 159-169 (1993)) and to promote cell adhesiveness (Tagaki et al., *Dev. Biol.* 170, 207-222 (1995)). Targeted disruption of NP-1 results in severe abnormalities in the trajectory of efferent fibers of the peripheral nervous system (Kitsukawa et al., *Neuron* 19, 995-1005 (1997)). Based on the these studies, it has been suggested that NP-1 is a neuronal cell recognition molecule that plays a role in axon growth and guidance (Kawakami et al., *J. Neurobiol.* 29, 1-17 (1995); He and Tessier-Lavigne, *Cell* 90, 739-751 (1997); Kitsukawa et al., *Neuron* 19, 995-1005 1997; Kolodkin et al., *Cell* 90, 753-762 (1997)).

15 Our results are the first to show that VEGF₁₆₅R/NP-1 is also expressed in adult tissues, in contrast to the earlier studies that have shown that NP-1 expression in *Xenopus*, chicken and mouse is limited to the developmental and early post-natal stages (Fujisawa et al., *Dev. Neurosci.* 17, 343-349 (1995); Kawakami et al., *J. Neurobiol.* 29, 1-17 (1995); Takagi et al., *Dev. Biol.* 170, 207-222 (1995)). For
20 example, in mice, NP-1 is expressed in the developing nervous system starting in the dorsal root ganglia at day 9 and ceases at day 15 (Kawakami et al., *J. Neurobiol.* 29, 1-17 (1995)). Our Northern blot analysis of human adult tissue demonstrates relatively high levels of VEGF₁₆₅R/NP-1 mRNA transcripts in heart, placenta, lung, liver, skeletal muscle, kidney and pancreas. Interestingly, there is very little relative
25 expression in adult brain, consistent with the mouse nervous system expression studies (Kawakami et al., *J. Neurobiol.* 29, 1-17 (1995)). VEGF₁₆₅R/NP-1 is also expressed in a number of cultured non-neuronal cell lines including EC and a variety of tumor-derived cells. A possible function of VEGF₁₆₅R/NP-1 in these cells is to mediate angiogenesis as will be discussed below.

30 In addition, NP-1 has been identified as a receptor for the collapsin/semaphorin family by expression cloning of a cDNA library obtained from

rat E14 spinal cord and dorsal root ganglion (DRG) tissue (He and Tessier-Lavigne, *Cell* 90, 739-751 (1997); Kolodkin et al., *Cell* 90, 753-762 (1997)). The collapsin/semaphorins (collapsin-D-1/Sema III/Sem D) comprise a large family of transmembrane and secreted glycoproteins that function in repulsive growth cone and axon guidance (Kolodkin et al., *Cell* 75, 1389-1399 (1993)). The repulsive effect of sema III for DRG cells was blocked by anti-NP-1 antibodies (He and Tessier-Lavigne, *Cell* 90, 739-751 (1997); Kolodkin et al., *Cell* 90, 753-762 (1997)). The K_d of sema III binding to NP-1, $0.15-3.25 \times 10^{-10}$ M (He and Tessier-Lavigne, *Cell* 90, 739-751 (1997); Kolodkin et al., *Cell* 90, 753-762 (1997)) is similar to that of VEGF₁₆₅ binding VEGF₁₆₅/NP-1, which is about 3×10^{-10} M. These results indicate that two structurally different ligands with markedly different biological activities, VEGF-induced stimulation of EC migration and proliferation on one hand, and sema III-induced chemorepulsion of neuronal cells, on the other hand, bind to the same receptor and with similar affinity. An interesting question is whether the two ligands bind to the same site on VEGF₁₆₅R/NP-1 or to different sites. VEGF₁₆₅R/NP-1 has five discrete domains in its ectodomain, and it has been suggested that this diversity of protein modules in NP-1 is consistent with the possibility of multiple binding ligands for NP-1 (Takagi et al., *Neuron* 7, 295-307 (1991); Feiner et al., *Neuron* 19 539-545 (1997); He and Tessier-Lavigne, *Cell* 90 739-751 (1997)). Preliminary analysis does not indicate any large degree of sequence homology between sema III and VEGF exon 7 which is responsible for VEGF binding to VEGF₁₆₅R/NP-1 (Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)). However there may be some 3-dimensional structural similarities between the two ligands. Since both neurons and blood vessels display branching and directional migration, the question also arises as to whether VEGF₁₆₅ displays any neuronal guidance activity and whether sema III has any EC growth factor activity. These possibilities have not been examined yet. However, it may be that VEGF requires two receptors, KDR and NP-1 for optimal EC growth factor activity (Soker et al., *J. Biol. Chem.* 272, 31582-31588 (1997)) and that sema III requires NP-1 and an as yet undetermined high affinity receptor for optimal chemorepulsive activity (Feiner et al., *Neuron* 19, 539-545 (1997); He and Tessier-Lavigne, *Cell* 90, 739-751 (1997); Kitsukawa et al., *Neuron* 19, 995-1005 (1997)), so

that the presence of NP-1 alone might not be sufficient for these ligands to display novel biological activities. Future studies will determine whether there are any connections between the mechanisms that regulate neurogenesis and angiogenesis.

5 VEGF₁₆₅R/NP-1 role angiogenesis

VEGF₁₆₅R/NP-1 modulates the binding of VEGF₁₆₅ to KDR, a high affinity RTK that is an important regulator of angiogenesis as evidenced by KDR knock out experiments in mice (Shalaby et al., *Nature* 376, 62-66 (1995)). The affinity of KDR for VEGF₁₆₅ is about 50 times greater than for VEGF₁₆₅R/NP-1 (Gitay-Goren et al., *J. Biol. Chem.* 287, 6003-6096 (1992); Waltenberger et al., *J. Biol. Chem.* 269, 26988-26995 (1994)). When VEGF₁₆₅R/NP-1 and KDR are co-expressed, the binding of ¹²⁵I-VEGF₁₆₅ to KDR is enhanced by about 4-fold compared to cells expressing KDR alone. The enhanced binding can be demonstrated in stable clones co-expressing VEGF₁₆₅R/NP-1 and KDR (PAE/KDR/NP-1 cells), and also in PAE/KDR cells transfected transiently with VEGF₁₆₅R/NP-1 cDNA where clonal selection does not take place. Conversely, when the binding of ¹²⁵I-VEGF₁₆₅ to VEGF₁₆₅R/NP-1 in PAE/KDR/NP-1 cells is inhibited completely by a GST fusion protein containing VEGF exons 7+8 (GST-Ex 7+8), the binding to KDR is inhibited substantially, down to the levels observed in cells expressing KDR alone. The fusion protein binds to VEGF₁₆₅R/NP-1 directly but is incapable of binding to KDR directly (Soker et al., *J. Biol. Chem.* 272, 31582-31588 (1997)). Although, not wishing to be bound by theory, we believe that VEGF₁₆₅ binds to VEGF₁₆₅R/NP-1 via the exon 7-encoded domain and facilitates VEGF₁₆₅ binding to KDR via the exon 4-encoded domain (Figure 11). VEGF₁₆₅R/NP-1, with its relatively high receptor/cell number, about $0.2-2 \times 10^5$ (Gitay-Goren et al., *J. Biol. Chem.* 287, 6003-6096 (1992); Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)), appears to serve to concentrate VEGF₁₆₅ on the cell surface, thereby providing greater access of VEGF₁₆₅ to KDR. Alternatively, binding to VEGF₁₆₅R/NP-1, VEGF₁₆₅ undergoes a conformational change that enhances its binding to KDR. The end result would be elevated KDR signaling and increased VEGF activity. Although we can demonstrate enhanced binding to KDR, to date we have not been able to demonstrate enhanced VEGF mitogenicity for PAE/KDR/NP-1

cells compared to PAE/KDR cells. One reason is that these cell lines do not proliferate readily in response to VEGF as do HUVEC (Waltenberger et al., *J. Biol. Chem.* 269, 26988-26995 (1994)). Nevertheless, we have shown that VEGF₁₆₅, which binds to both KDR and VEGF₁₆₅R/NP-1, is a better mitogen for HUVEC than is VEGF₁₂₁, which
5 binds only to KDR (Keyt et al., *J. Biol. Chem.* 271, 5638-5646 (1996b); Soker et al., *J. Biol. Chem.* 272, 31582-31588 (1997)). Furthermore, inhibiting VEGF₁₆₅ binding to VEGF₁₆₅R/NP-1 on HUVEC by GST-EX 7+8, inhibits binding to KDR and also inhibits VEGF₁₆₅-induced HUVEC proliferation, down to the level induced by VEGF₁₂₁ (Soker et al., *J. Biol. Chem.* 272, 31582-31588 (1997)). Taken together,
10 these results suggest a role for VEGF₁₆₅R/NP-1 in mediating VEGF₁₆₅, but not VEGF₁₂₁ mitogenic activity. The concept that dual receptors regulate growth factor binding and activity has been previously demonstrated for TGF- β , bFGF and NGF (Lopez-Casillas et al., *Cell* 67, 785-795 (1991); Yayon et al., *Cell* 64, 841-848 (1991); Barbacid, *Curr. Opin. Cell Biol.* 7, 148-155 (1995)).

15 Another connection between VEGF₁₆₅R/NP-1 and angiogenesis comes from studies in which NP-1 was overexpressed ectopically in transgenic mice (Kitsuskawa et al., *Develop.* 121, 4309-4318 (1995)). NP-1 overexpression resulted in embryonic lethality and the mice died *in utero* no later than on embryonic day 15.5 and those that survived the best had lower levels of NP-1 expression. Mice overexpressing NP-1
20 displayed morphologic abnormalities in a limited number of non-neural tissues such as blood vessels, the heart and the limbs. NP-1 was expressed in both the EC and in the mesenchymal cells surrounding the EC. The embryos possessed excess and abnormal capillaries and blood vessels compared to normal counterparts and in some cases dilated blood vessels as well. Some of the chimeric mice showed hemorrhaging,
25 mainly in the head and neck. These results are consistent with the possibility that ectopic overexpression of VEGF₁₆₅R/NP-1 results in inappropriate VEGF₁₆₅ activity, thereby mediating enhanced and/or aberrant angiogenesis. Another piece of evidence for a link between NP-1 and angiogenesis comes from a recent report showing that in mice targeted for disruption of the NP-1 gene, the embryos have severe abnormalities
30 in the peripheral nervous system but that their death *in utero* at days 10.5-12.5 is most

probably due to anomalies in the cardiovascular system (Kitsukawa et al., *Neuron* 19, 995-1005 (1997)).

VEGF₁₆₅R/NP-1 is associated with tumor-derived cells

5 The greatest degree of VEGF₁₆₅R/NP-1 expression that we have detected so far occurs in tumor-derived cells such as 231 breast carcinoma cells and PC3 prostate carcinoma cells, far more than occurs in HUVEC. The tumor cells express abundant levels of VEGF₁₆₅R/NP-1 mRNA and about 200,000 VEGF₁₆₅ receptors/cell (Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)). On the other hand, these tumor cells do not
10 express KDR or Flt-1 so that VEGF₁₆₅R/NP-1 is the only VEGF receptor associated with these cells. The tumor cells are therefore useful for testing whether VEGF₁₆₅R/NP-1 is a functional receptor for VEGF₁₆₅ in the absence of a KDR background. To date, we have not been able to show that VEGF₁₆₅R/NP-1 mediates a VEGF₁₆₅ signal in tumor-derived cells as measured by receptor tyrosine
15 phosphorylation. Nevertheless, VEGF₁₆₅ might have an effect on tumor cells by inducing some, as yet undetermined activity such as enhanced survival, differentiation, or motility. A recent report has demonstrated that glioma cells express a 190 kDa protein that binds VEGF₁₆₅ but not VEGF₁₂₁ efficiently (Omura et al., *J. Biol. Chem.* 272, 23317-23322 (1997)). No stimulation of tyrosine phosphorylation could be
20 demonstrated upon binding of VEGF₁₆₅ to this receptor. Whether the 190 kDa isoform-specific receptor is related to VEGF₁₆₅R/NP-1 is not known presently.

VEGF₁₆₅R/NP-1 may have a storage and sequestration function for VEGF₁₆₅. One might envision that VEGF₁₆₅ is produced by a tumor cell and binds to VEGF₁₆₅R/NP-1 on that cell via the exon 7-encoded domain (Soker et al., *J. Biol. Chem.* 271, 5761-5767 (1996)). The stored VEGF₁₆₅ could be then released to
25 stimulate tumor angiogenesis in a paracrine manner. Alternatively, VEGF₁₆₅R/NP-1 may mediate a juxtacrine effect in which VEGF₁₆₅ is bound to VEGF₁₆₅R/NP-1 on a tumor cell via the exon 7-encoded domain and is also bound to KDR on a neighboring EC via the exon 4-encoded domain (Keyt et al., *J. Biol. Chem.* 271, 5638-5646
30 (1996b)). Such a mechanism could result in a more efficient way for tumor cells to attract EC, thereby enhancing tumor angiogenesis.

In summary, we have demonstrated by independent purification and expression cloning methods that the VEGF isoform specific receptor, VEGF₁₆₅R, is identical to NP-1, a cell surface protein previously identified as playing a role in embryonic development of the nervous system and as being a receptor for the
5 collapsins/semaphorins. Furthermore, binding to VEGF₁₆₅R/NP-1 enhances the binding of VEGF₁₆₅ to KDR on EC and tumor cells.

Experimental Rationale

We have discovered that tumor cell neuropilin-1 mediates tumor cell motility
10 and thereby metastasis. In a Boyden chamber motility assay, VEGF₁₆₅ (50 ng/ml) stimulates 231 breast carcinoma cell motility in a dose-response manner, with a maximal 2-fold stimulation (Fig. 15A). On the other hand, VEGF₁₂₁ has no effect on motility of these cells (Fig. 15B). Since 231 cells do not express KDR or Flt-1, these results suggest that tumor cells are directly responsive to VEGF₁₆₅ and that VEGF₁₆₅
15 might signal tumor cells via neuropilin-1. Possible candidates for mediating VEGF₁₆₅-induced motility of carcinoma cells are PI3-kinase (PI3-K) (Carpenter, et al. (1996) *Curr. Opin. Cell Biol.* 8: 153-158.). Since 231 cells do not express KDR or Flt-1, these results suggest that tumor cells are directly responsive to VEGF₁₆₅ and that VEGF₁₆₅ might signal tumor cells via neuropilin-1.

20 The other type of evidence is that neuropilin-1 expression might be associated with tumor cell motility. We have analyzed two variants of Dunning rat prostate carcinoma cells, AT2.1 cells, which are of low motility and low metastatic potential, and AT3.1 cells, which are highly motile, and metastatic. Cross-linking and Northern blot analysis show that AT3.1 cells express abundant neuropilin-1, capable of binding
25 VEGF₁₆₅, while AT2.1 cells don't express neuropilin-1 (Fig. 16). Immunostaining of tumor sections confirms the expression of neuropilin-1 in AT3.1, but not AT2.1 tumors (Fig. 17). Furthermore, the immunostaining shows that in subcutaneous AT3.1 and PC3 tumors, the tumor cells expressing neuropilin-1 are found preferentially at the invading front of the tumor/dermis boundary (Fig. 17). To determine more directly
30 whether neuropilin-1 expression is correlated with enhanced motility, neuropilin-1 was overexpressed in AT2.1 cells (Fig. 18). Three stable clones of AT2.1 cells overexpressing neuropilin-1 had enhanced motility in the Boyden chamber assay.

These results indicate that expression of neuropilin-1 in AT2.1 cells enhances their motility. Taken together, it appears that neuropilin-1 expression on tumor cells is associated with the motile, metastatic phenotype.

5 EXAMPLE 2

Experimental Procedures

1. Collapsin/semaphorins. Expression plasmids for expressing and purifying His-tagged collapsin-1 from transfected 293T cells can be produced according to the
10 methods of (Koppel, et al. (1998) *J. Biol. Chem.* 273: 15708-15713, Feiner, et al. (1997) *Neuron* 19: 539-545.). Expression vectors for expressing sema E and sema IV alkaline phosphate (AP) conjugates in cells are disclosed in (He Z, Tessier-Lavigne M. (1997). Neuropilin is a receptor for the axonal chemorepellent semaphorin III. *Cell* 90: 739-751.). Migration was measured in a Boyden chamber Falk, et al., *J. Immunol.*
15 118:239-247 (1980) with increasing concentration of recombinant chick collapsin-1 in the bottom well and PAE cell transfectants in the upper well.
2. Aortic Ring Assay. 200 gram rats were sacrificed and the aorta is dissected
20 between the aortic arch and kidney artery and the adipofibrotic tissue around the aorta was removed. Aortic rings were sliced at 1 mm intervals and embedded in type I collagen gels. Each ring was cultured in one well of a 48-well plate with serum-free endothelial cell medium (GIBCO). The number of microvessels were counted in each ring using a phase microscope (Miao, et al. (1997). *J. Clin. Invest.* 99: 1565-1575.).

We established several endothelial cell lines by transfection of parental porcine aortic endothelial cells (PAE), which normally do not express VEGF receptors (Soker, et al.(1998)*Cell* 92: 735-745). The cell lines included PAE cells expressing neuropilin-1 alone (PAE/NP1), PAE cells expressing KDR alone (PAE/KDR) and
5 PAE cells expressing both neuropilin-1 and KDR (PAE/NP1/KDR). Collapsin-1 was obtained from Dr. Jon Raper, University of Pennsylvania (Luo, et al.(1993)*Cell* 75: 217-227.).

Binding studies demonstrated that ^{125}I -collapsin-1 could bind to PAE/NP1 cells and PAE/NP1/KDR cells but not at all to PAE or PAE/KDR cells.

10 In a Boyden chamber assay, collapsin-1 at 50-100 collapsin units/ml (CU) inhibited the basal migration of PAE/NP and PAE/NP1/KDR cells by 70% but had no inhibitory effect, whatsoever, on basal PAE or PAE/KDR cell migration (Fig. 20). This effect is fairly potent since 1 CU represents about 3 ng/ml protein. The collapsin-1 inhibitory effect was inhibited by anti-neuropilin-1 antibodies. These results indicate
15 that collapsins can inhibit the migration of non-neuronal endothelial cells as long as they express neuropilin-1.

Collapsin-1 inhibited the migration of PAE/NP and PAE/NP/KDR cells in the presence of VEGF₁₆₅, to the same degree, the baseline being higher. We have also found that addition of collapsin in a rat aortic ring assay (a model for angiogenesis *in*
20 *vitro*) inhibits the migration of endothelial cells out of the ring, and endothelial tube formation (Fig. 21).

25

The references cited throughout the specification are incorporated herein by reference.

The present invention has been described with reference to specific embodiments. However, this application is intended to cover those changes and
30 substitutions which may be made by those skilled in the art without departing from the spirit and the scope of the appended claims.

What is claimed:

1. A neuropilin antagonist that binds neuropilin and has VEGF antagonist activity as determined by the human umbilical vein endothelial cell (HUVEC) proliferation assay using VEGF₁₆₅

2. The neuropilin antagonist of claim 1, wherein the antagonist is an antibody that specifically inhibits binding of VEGF to a neuropilin receptor.

3. The neuropilin antagonist of claim 1, wherein the antagonist is a member of the semaphorin/collapsin family or a fragment thereof.

4. The neuropilin antagonist of claim 1, wherein the member of the semaphorin/collapsin family is collapsin-1. = SEMA 3A

5. An antibody directed against a neuropilin receptor, wherein said antibody specifically inhibits binding of VEGF to the receptor.

6. The antibody of claim 5, wherein the neuropilin is NP-1 or NP-2.

7. A method for identifying an antagonist which binds to a neuropilin, comprising exposing the neuropilin to the molecule suspected of binding thereto and determining binding of the molecule to the receptor.

8. The method of claim 7, wherein the neuropilin is NP-1 or NP-2.

9. A method of inhibiting metastasis in a patient having malignant cells which comprises:

(a) determining whether the patient's malignant cells express a neuropilin, and if they do adding a compound that interferes with the neuropilin.

10. The method of claim 9, wherein the compound interferes with the binding activity of the neuropilin.
11. The method of claim 10, wherein the compound is a antibody that specifically binds neuropilin or a neuropilin antagonist.
12. The method of claim 9, wherein the compound interferes with neuropilin expression.
13. The method of claim 11, wherein the compound is a member of the semaphorin/collapsin family or a fragment thereof.
- 14.. The method of claim 12, wherein the member of the semaphorin/collapsin family is collapsin-1.
15. The method of claim 9, wherein the malignant cell is a breast or prostate cell or a melanoma.
16. The method of claim 9, wherein the neuropilin is VEGF₁₆₅R/NP-1 or NP-2.
17. Use of a member of the semaphorin/collapsin family in the preparation of a medicament for the treatment of a disease or disorder associated with VEGF.

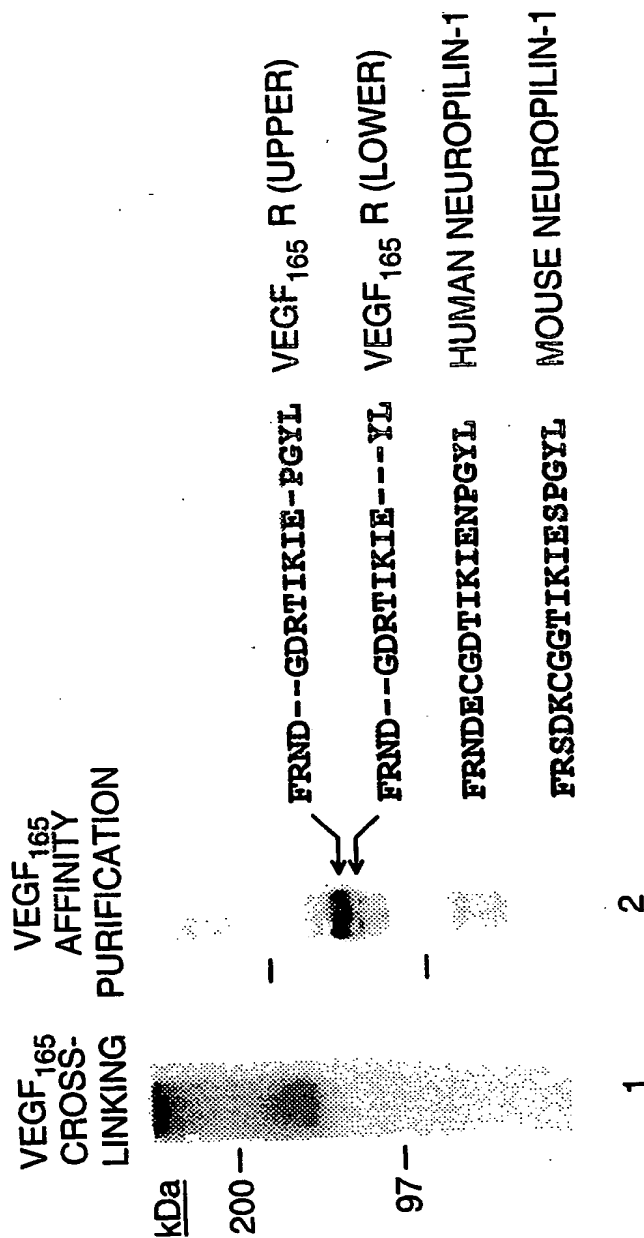


FIG. 1



FIG. 2A

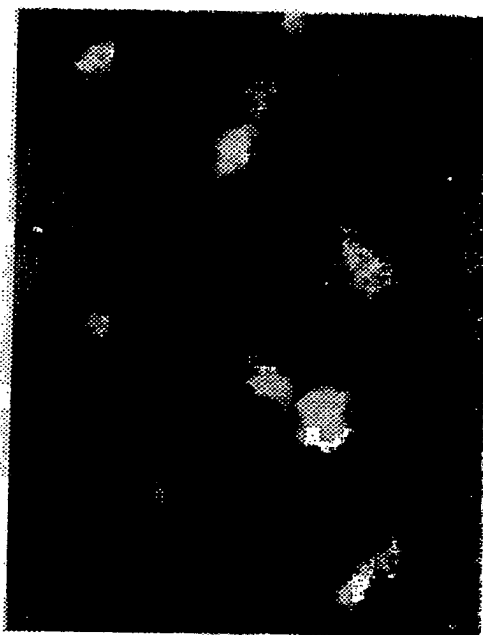


FIG. 2B

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1 MERGLPLLCAVLALVLAPAGAFERNDKCGDTIKIESPGYLTSPPGPHSYHPSEKCEWLQAPDPYQIRIMIN 70
 71 FNPFDLED RDCKYDYVEVFDGENENHGRKFCGKIAPPPVSSGPFLEIKFVSDYETHGAGFSIRYEI 140
 141 FKRGPESQNYTTPSGVIKSPGFPEKYPNSLECTYIVFAPKMSEIILEFESFDLEPDSNPPGGMFCRYDR 210
 211 LEIWDGFPDVGPHIGRYCGQKTPGRIRSSGILSMVFYTDSAIAKEGFSANYSVLQSSVSEDFKCMEALG 280
 281 MESGEIHSQITASSQYSTNWSAERSRLNYPENGWTPGEDSYREWIQVDLGLLRFTAVGTQGAISKETK 350
 351 KKYVVKTYKIDVSSNGEDWITIKEGNKPVLFQGNTPDVTDVVAVFPKPLITRFVRIKPATWETGISMRFE 420
 421 VYGCKITDYPCSGMLGMVSLISDSQITSSNQGDRNWMPENIRLVTSRSGWALPPAPHSYINEWLQIDLG 490
 491 EEKIVRGIIIQGCKHRENKVFMRKFKIGYSNNGSDWKIMDDSKRKAKSFEGNNNYDTPELRTPALSTR 560
 561 FIRIYPERATHGGLRLMELLGCEVEAPTAGPTTPNGNLVDECDDQANCHSGTGDDFQLTGGTTVLATE 630
 631 KPTVIDSTIQSEFPTYGFNCFEGWGSHTFCHWEHDNHVQLKWSVLTSKTPIQDHTGDGNFIYSQADEN 700
 701 QKGKVARLVSPVYSONSAHCMTFWYHMSGSHVGTLRVKLRYQKPEEYDQLVWMAIGHQGDHWKEGRVLL 770
 771 HKSLKLYQVIFEGEIGKGNLGGIAVDDISINNHISQEDCAKPADLDKKNPEIKIDETGSTPGYEGEGED 840
 841 KNISRKPGNVLKTLDPILITIIAMSALGVLLGAVCGVVLYCACW^hNHNGMSERNLSALENYNFELVDGVKLK 910
 911 KDKLNTQSTYSEA 923

FIG. 3

FIG. 4A
FIG. 4B

FIG. 4

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COMPARATIVE DEDUCED AMINO ACID SEQUENCES
OF HUMAN VEGF₁₆₅ R/NP AND VEGF₁₆₅ R/NP-1

VEGF ₁₆₅ R/NP-2	1	MDMF-PLTW-VFLALYFSRHQVRGQPOPPCGG-RLNSK--DA-----GY	50
VEGF ₁₆₅ R/NP-1		MERGLPLLCAV-LAL-----VLA-PA---GAFR-NDKCGDTIKIESPGY	
NP-2	51	ITSPGYPDY-PSHQNCW-IVYAPENQKIVLNFNPEFEIEKHDCKYDF	100
NP-1		LTSPGYPHSYHPSEK-CEWLIQ-APDPYQIRIMINFNPHFDLEDRCXYDY	
NP-2	101	IEIRDGSEADLLGKHCGNIAPPTIISSGSMLYIKFTSDYARQGAGFSL	150
NP-1		VEVFDGENENGHRGKFCGKIAPPPVSSGPFLEFIKFVSDYETHGAGFSI	
NP-2	151	RYEIFKTGSEDCSKNFTSPNGTIESPGFPEKYPHN-LDCTFTIL-AKPKM	200
NP-1		RYEIFKRGPE-CSQNYTTPSGVIKSPGFPEKYP-NSLECTY-IVFA-PKM	
NP-2	201	-EIIQLQFLIFDLEHD--PLQVGEGD-CKYDWLDIWDGIPHVGPLIGKYCG	250
NP-1		SEIILEFESEFDLEPDSNPP--G-GMFCRYDRLEIWDGFDPVGP HIGRYCG	
NP-2	251	TKTPSELRSSTGILSLTFHTDMAVAKDGSARYYLVHQEPL-ENFQCNVP	300
NP-1		QKTPGRIRSSSGILSMVPYTDSAIAKEGFSANYS-VLQSSVSEDFKCMFA	
NP-2	301	LGMESGAIANEQISASSTYS DGRWTPQQSRHLHGDDNGWTPNLD SNKEYLQ	350
NP-1		LGMESGEIHSDQITASSQYSTN--WSAERSRLNYPENGWTPGEDSYREWIQ	
NP-2	351	VDL---REFLTMLTAITQGAISRETQNGYYVKS YKLEVSTNGEDWMVYRH	400
NP-1		VDLGLURFVT---AVGTQGAISKETKKYYVKT YKIDVSSNGEDWITIKE	
NP-2	401	GKNHK-V-FQAN-NDATEVVLN---KLHAPLLTRFVRIRPQTWHSGIALR	450
NP-1		G-N-KPVLFOGNTNP-TDVVVAVFPK---PLITRFVRIKPATWETGISM R	
NP-2	451	LELEGCRVTDAPCSMKLGLSLG LIADSQISASSTQEYL-WSPSAARLVSS	500
NP-1		FEVYGCKITDYP CSGMLGMVSGLI SDSQIT-SSNQGDRNWM PENIRL VTS	

FIG. 4A

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NP-2 501 RSGWF-PRIPQAQPG---EWLQVDLGTPTKTVKGVIIQARGGDSITAVE 550
NP-1 RSGWALP--P-A-PHSYINELQIDLGEKIVRGIIIQG--GKHRENKV--
NP-2 551 ARAFVRKFKVSYSLNGKDWEYIQDP--RTQOPKLFEGNMHYDTPDIRRFD 600
NP-1 ---FMRKFKIGYSNNGSDWKIMDDSKRKA--KSFEGNNNYDTPELRTF--
NP-2 601 PIPAQYVRV---YPERWSPA--GI-GMRLEVLGCDWTDKPTVE--TLGP 650
NP-1 P--ALSTRFIRIYPER---AFHGGLGLRMEILIGCE-----VEAPTAGE
NP-2 651 TVKSEETTPYPTTEEEATECGE---NC-SFE-DDKDLQ-----L-----P- 700
NP-1 T-----T--PNGNLVD--ECDDDDQANCHSGTGDDFQLTGTTLATEKPT
NP-2 701 ---S-----GENCFD-----FLEPCGMYD-BA--KW--LRTT 750
NP-1 VIDSTIQSEFFPTYGFENCEFGWGHKTF-----CHWEHDNHVQLKNSVL-T-
NP-2 751 WASSSPN-DRTFPDDRNFLRLQSDS-QREGQYARLISPPVHLPRSPVCM 800
NP-1 --SKTGPIQDHTG-DG-NFIYSQADENQK-GKVARLVSPVYSONSAHCM
NP-2 801 EFQYQATG---G--RGVAL--QVVREASQESKLLWV-IREQGGGEWKHGR 850
NP-1 TFWYHMSGSHVGTLR-VKLRYQKPEEYDQ---LVWMAIGH-QGDHWKEGR
NP-2 851 IILP-SYDMEYQ-IVFEGVIGKGRSGEIAIDOIRI-----STDVPLENCME 900
NP-1 VLLHKSLKL-YQVI-FEGEIGKGNLGGIAVDDISINNHISQ-----EDCAK
NP-2 901 PISAFAGENFKVDIPEIHERE-G-----YEDEIDDEYVDWSNSSATSGS 950
NP-1 P--ADLDK--KN--PEIKIDETGSTPGYEGEG--EG--DK-NISRKP-GN
NP-2 951 GAPSTDKEKSWLYTLDPILITIIAMSSLGVLGATCAGLLLYCTCSYGL 1000
NP-1 VL-----K-----TLDPILITIIAMSA LGVLLGAVC-GVVLYCACWHNGM
NP-2 1001 SSR--SCTTLENYNFELYDG--LKHVKVMNHQKCCSEA 1038
NP-1 SERNLSA--LENYNFELVDGVKLGK-KDKLNTQSTYSEA

FIG. 4B

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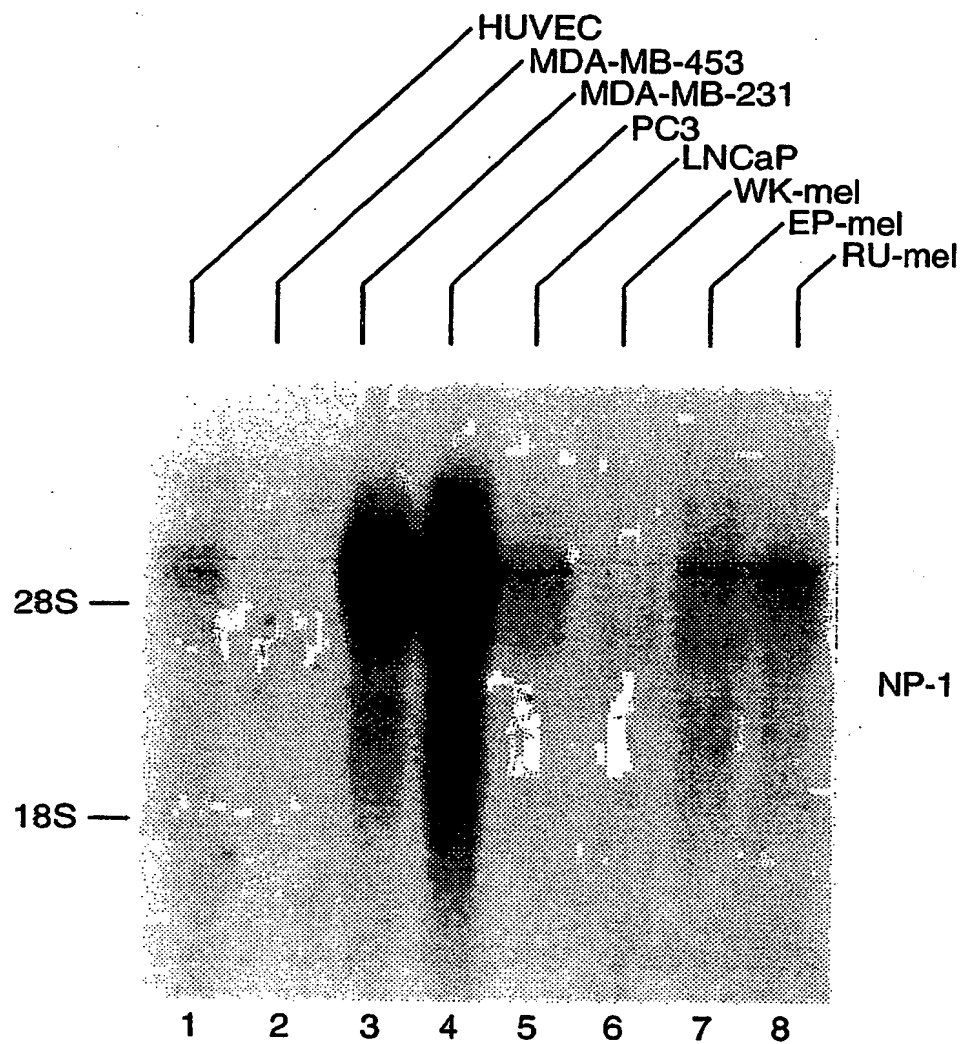


FIG. 5

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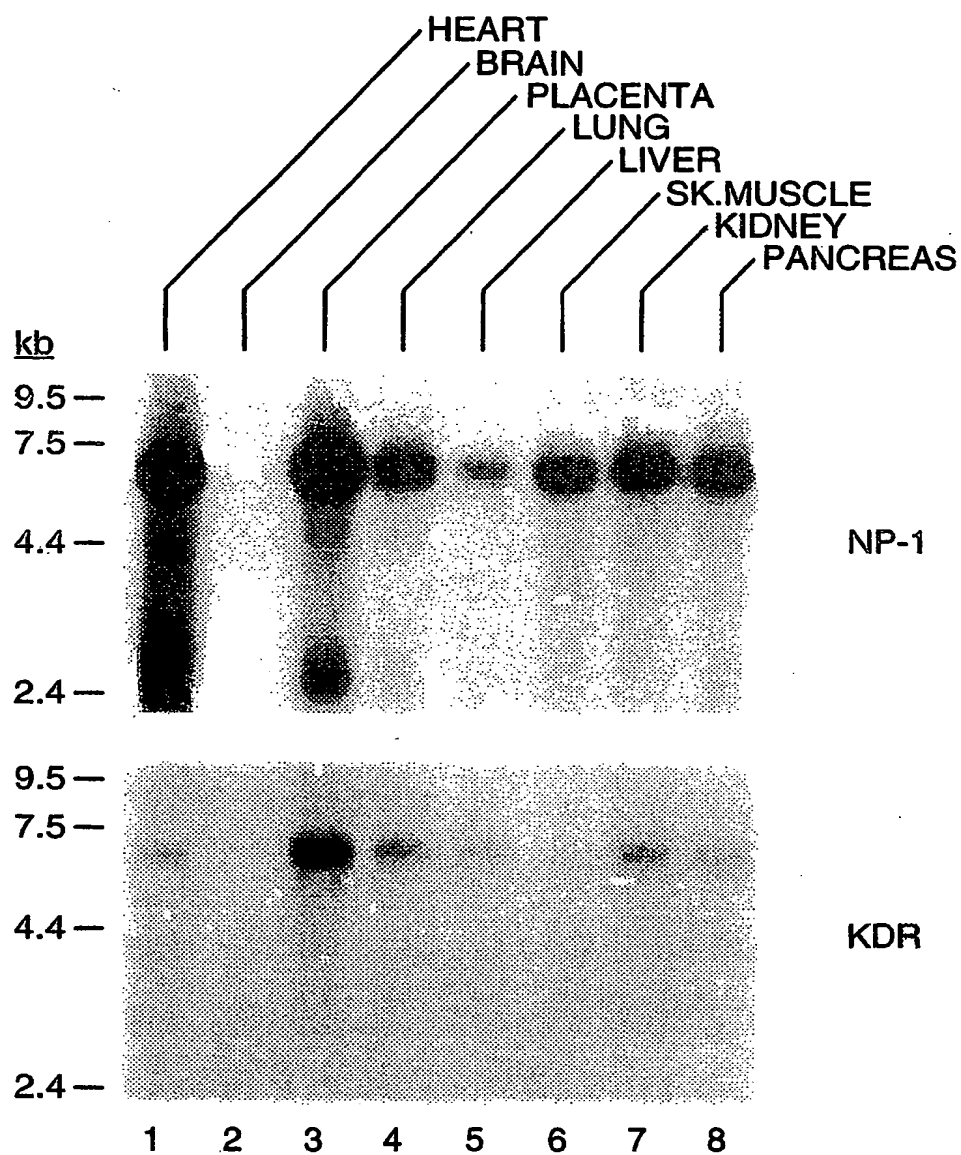


FIG. 6

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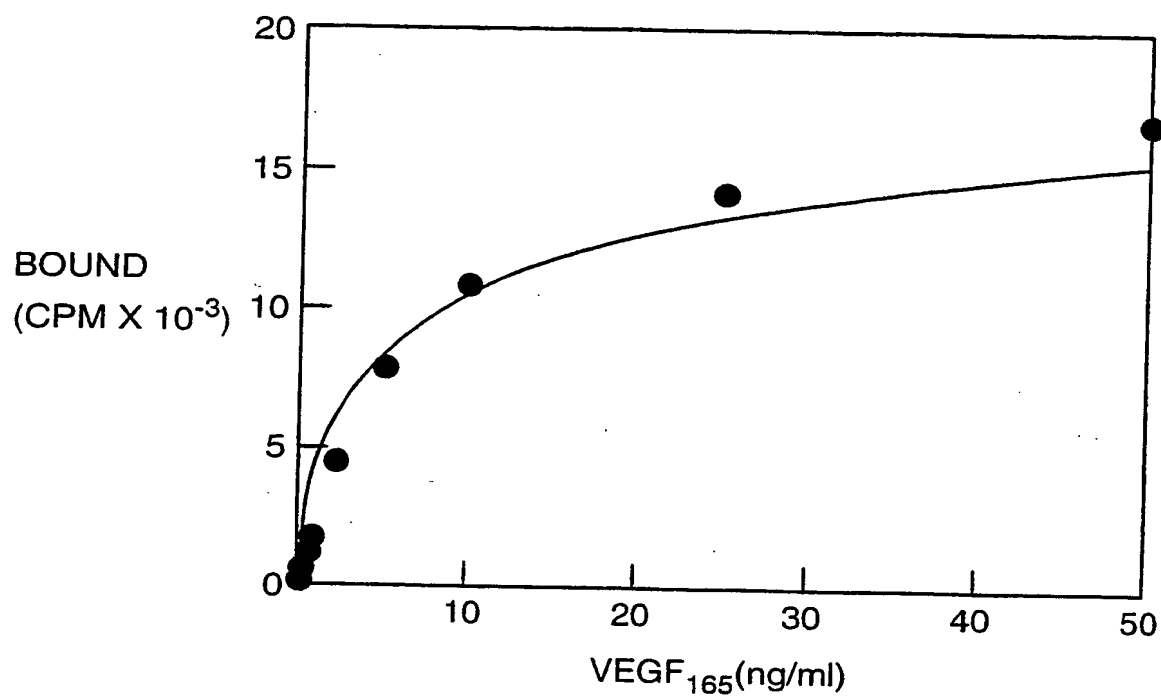


FIG. 7A

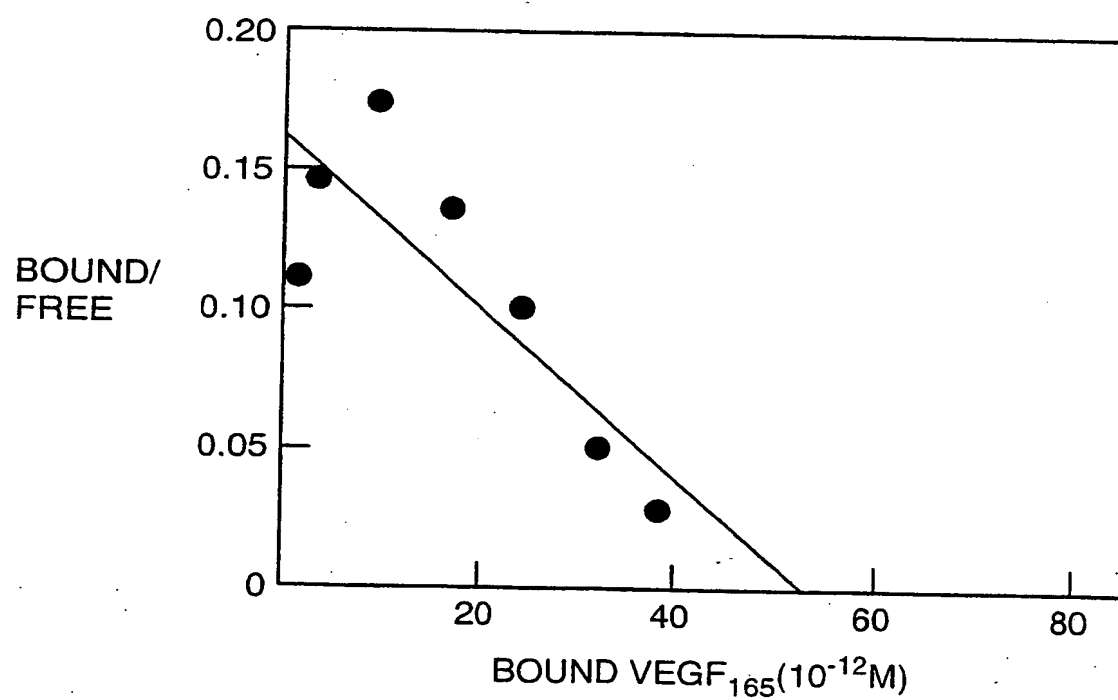


FIG. 7B

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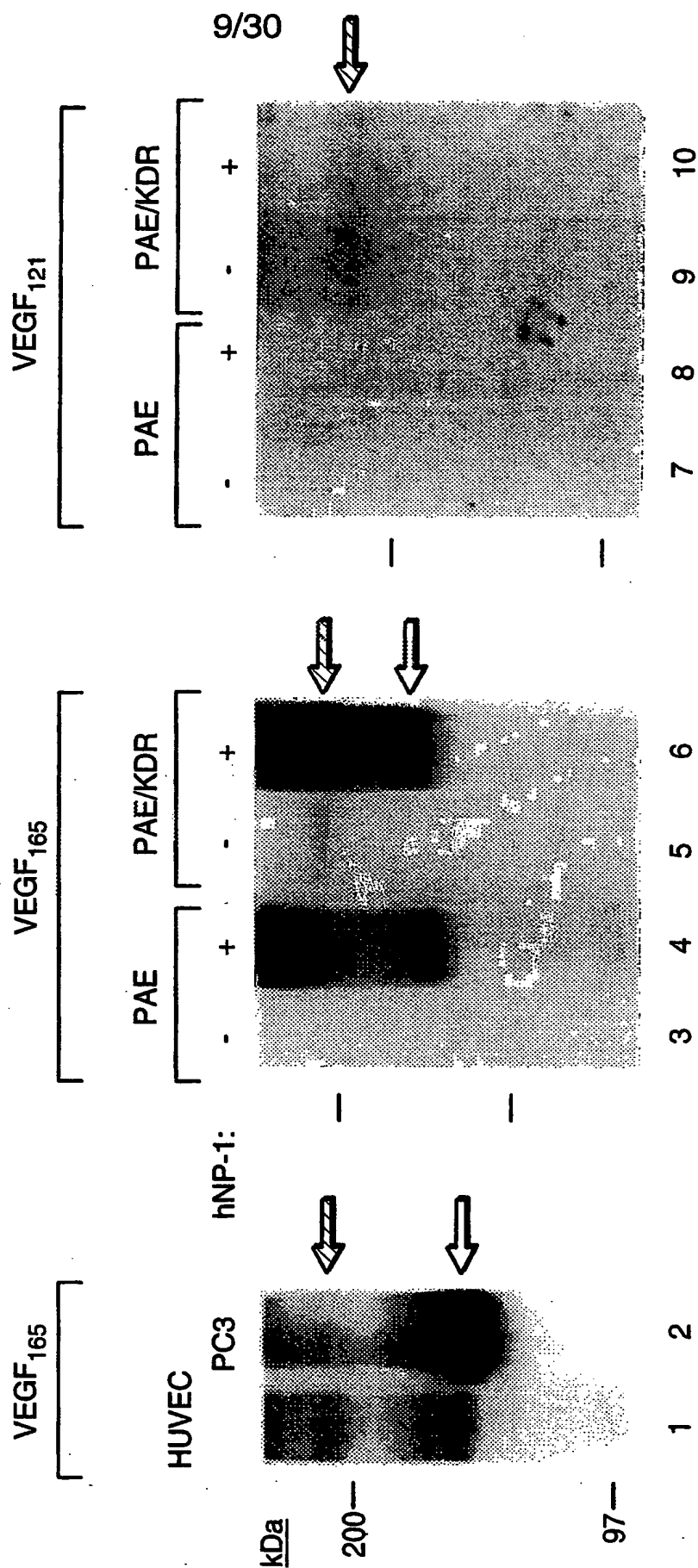


FIG. 8

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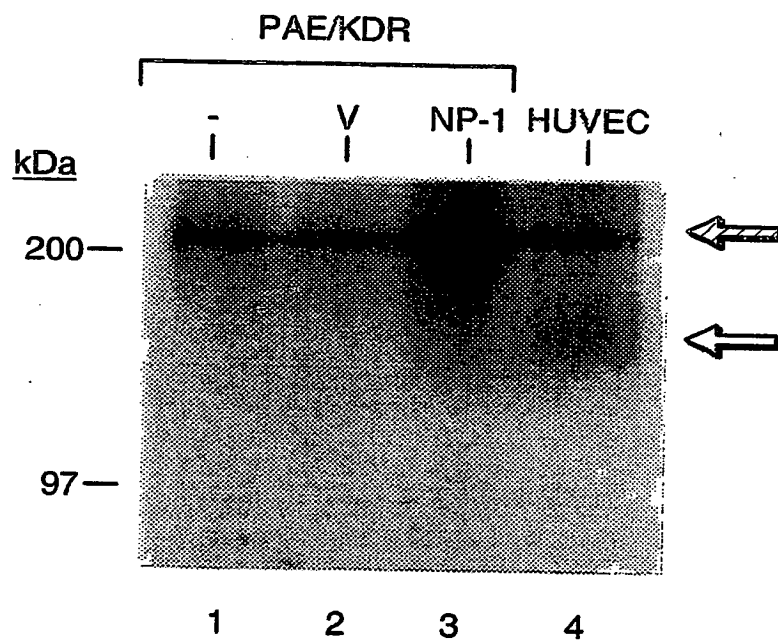


FIG. 9

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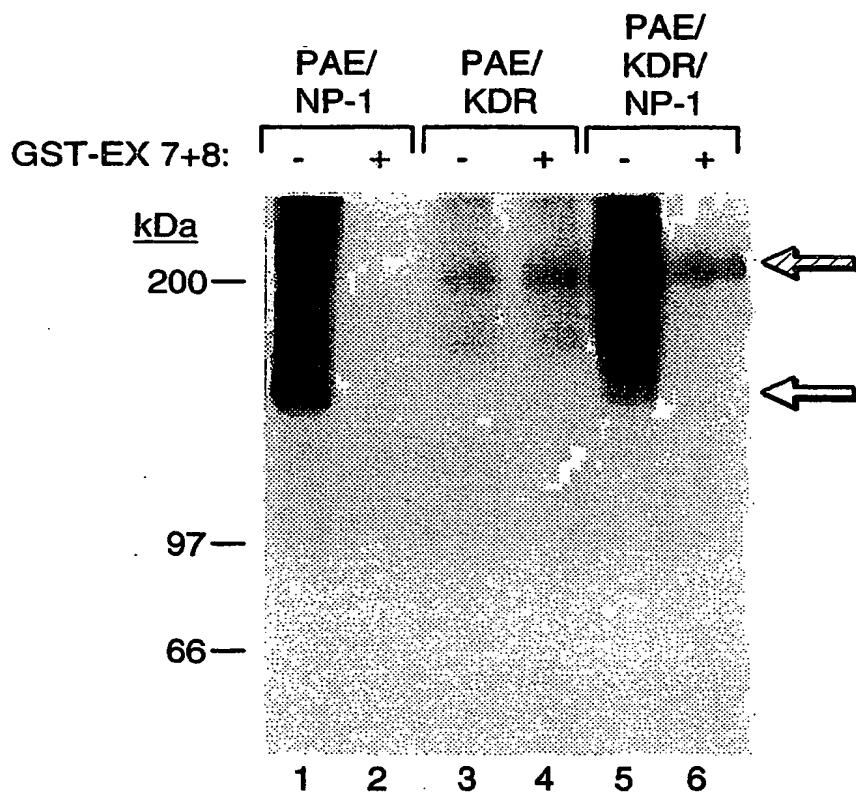
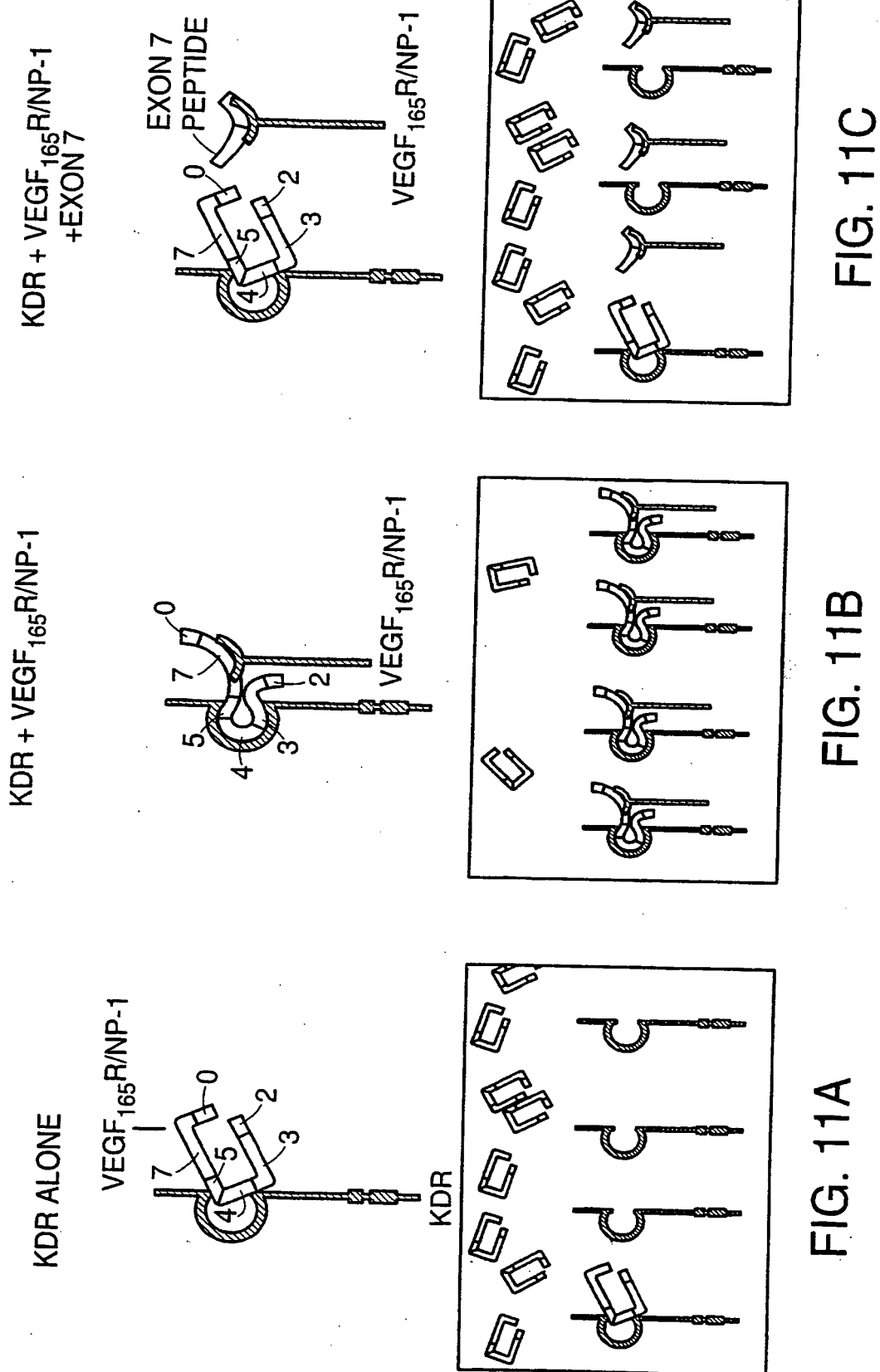


FIG. 10

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HUMN NEUROPILIN-2 AMINO ACID SEQUENCE:

MDMFPLTWVFLALYFSRHQVRGQPDPPCGGRLNSKDAGYITSPGY PQDYPSHQN
CEWIVYAPEPNQKIVLNFNPHFEIEKHDC KYDFIEIRDGDSE S ADLLGKHCGNIAPP
TISSGSMLYIKFTSDYARQGAGFSLRYE IFKTGSEDCSKNFTSPNGTIESPGFPEK
YPHNLDCTFTILAKPKMEIILQFLIFDLEHDPLQVGE GDCKYDWLDIWDGIPHVGPL
IGKYCGTKTPSELRSSTGILSLTFHTDMAVAKDGF SARYYLVHQEPLENFQCNVP
LGMESGRIANEQISASSTYS DGRWTPQQSRLHGDDNGWTPNLDSNKEYLQVDLR
FLTMLTAIATQGAISRETQNGYYVKS YKLEVSTNGEDWMVYRHGKNHKVFQANN
DATEVVLNKLHAPLLTRFVRIRPQTWHSGIALRLELFGCRVTDAPCSNMLGMLS
GLIADSQISASSTQEYLWSPSAARLVSSRS GWFPRI PQAQPGEEWLQVDLGTPK
TVKGVIIGGARGGDSITAVEARAFVRKFKVS YSLNGKDWEYIQDPRTQQPKLFEG
NMHYDTPDIRRFDPIPAQYVRVYPERWSPAGIGMRLEVLGCDWTD SKPTVETLG
PTVKSEETTTPTYPTEEEEATECGENCSFEDDKDLQLPSGFNCNFD FLEPCGWMYD
HAKWLRTTWASSSSPNDRTFPDDRNFLRLQSDSQREGQYARLISPPVHLPRSPV
CMEFQYQATGGRGVALQVVREASQESKLLWVIRE DQGGGEWKHGRIILPSYDMEYQ
IVFEGVIGKGRSGEIAIDDIRISTDVPLENCMEPISAFAGENFKVDIPEIHEREGYED
EIDDEYEVDWSNSSSATSGSGAPSTDKEKSWLYTLDPI LITIIAMSSLGVLLGAT
GAGLLLYCTCSYSGLSRSCTTLENYNFELYDGLKHKVKMNHQKCCSEA*

FIG. 12

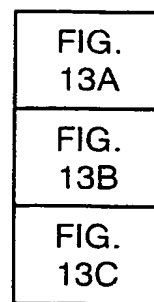


FIG. 13

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```

gaatcggca cgaggggaaa ataaaagaga gaaaaacaca aagattttaa caagaaacct    60
acgaacccag ctctggaaag agccaccttc tccaaaatgg atatgtttcc tctcacctgg    120
gttttcttag ccctctactt ttcaagacac caagtgaag gccaaccaga cccaccgtgc    180
ggaggtcgtt tgaattccaa agatgctggc tatacacct ctccggta ccccaggac    240
taccctccc accagaactg cgagtggatt gttacgcc ccgaaccaa ccagaagatt    300
gtcctcaact tcaacccctca ctttgaatc gagaagcac actgcaagta tgactttatc    360
gagattcggg atggggacag tgaatccgca gacctcctgg gcaaacactg tgggaacatc    420
gccccgcca ccatactctc ctctctgccc atgctctaca tcaagttcac ctccgactac    480
gcccggcagg gggcaggctt ctctctgccc tacgagatct tcaagacagg ctctgaagat    540
tgctcaaaaa acttcacaag ccccaacggg accatcgaat ctctgggtt tcctgagaag    600
tatccacaca acttggactg cacctttacc atcctggcca aacccaagat ggagatcatc    660
ctgcagttcc tgatctttga cctggagcat ctgggatggc attccacatg ttggccccct    720
aagtacgatt ggctggacat ctctgaactt cgttcacatga cggggatcct ctccctgacc    780
tactgtggga ccaaaacacc ctctgaactt ggcttctctg cggttacta cctggtccac    840
ttcacacagg acatggcggt tcaagtgaat gtctctcttg gcatggagtc tggccggatt    900
caagagccac tagagaactt agatcagtgc ctcatctacc tactctgatg ggaggtggac    960
gctaatgaac agatcagtgc ctcatctacc tactctgatg ggaggtggac ccctcaacaa    1020
agccggctcc atggtgatga caatggctgg acccccaact tggattccaa caaggagtat    1080
ctccagggtg acctgcgctt tttaaccatg ctcaacggcca tcgcaacaca gggagcgatt    1140
tccagggaaa cacagaatgg ctactacgtc aaatcctaca agctggaagt cagcactaat    1200

```

FIG. 13A

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1260 ggagaggact ggatggtgta cggcatggc aaaaccaca aggtatttca agccaacaac
1320 gatgcaactg aggtggttct gaacaagctc cacgctccac tgctgacaag gtttgtaga
1380 atccgccctc agacctggca ctcaggatc gccctccggc tggagctctt cggctgccgg
1440 gtcacagatg ctccctgctc caacatgctg gggatgctct caggcctcat tgcagactcc
1500 cagatctccg cctcttccac ccaggaatac ctctggagcc ccagtgcagc ccgcctggtc
1560 agcagccgct cgggctggtt ccctcgaatc cctcaggccc agcccggtga ggagtggctt
1620 caggtagatc tgggaacacc caagacagtg aaaggtgtca tcatccaggg agcccgcgga
1680 ggagacagta tcactgctgt ggaagccaga gcatttgtgc gcaagttaa agtctcctac
1740 agcctaaacg gcaaggactg ggaatacatt caggaccca ggaccagca gccaaagctg
1800 ttcgaaggga acatgcacta tgacacccct gacatccgaa ggtttgacc cattccggca
1860 cagtatgtgc gggatatccc ggagaggtag tgccggcggc ggattgggat gcggctggag
1920 gtgctgggct gtgactggac agactccaag ccacggtag agacgctggg acccaactgtg
1980 aagagcgaag agacaaccac cccctacccc accgaagagg aggccacaga gtgtggggag
2040 aactgcagct ttgaggatga caaagatttg cagctccctt cgggattcaa ttgcaactc
2100 gatttccctc aggagccctg tggttggatg tatgaccatg ccaagtggct ccggaccacc
2160 tgggccagca gctccagccc aaacgaccgg acgtttccag atgacaggaa ttcttgccg
2220 ctgcagagtg acagccagag agagggccag tatgccggc tcatcagccc ccctgtccac
2280 ctgccccgaa gccgggtgtg catggagttc cagtaccagg ccacgggcgg ccgcggggtg
2340 gcgctgcagg tggtcgggga agccagccag gagagcaagt tgctgtgggt catccgtgag
2400 gaccagggcg gcgagtggaa gcacggggcg atcatcctgc ccagctacga catggagtag

FIG. 13B

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cagattgtgt tcgaggagtg gatagggaaa ggacgttccg gagagattgc cattgatgac 2460
attcggataa gcactgatgt cccactggag aactgcatgg aaccatctc ggcttttgca 2520
ggtgagaatt ttaaagtga catccagaa atacatgaga gagaaggata tgaagatgaa 2580
attgatgatg aatacgaggt ggactggagc aattcttctt ctgcaacctc aggtctctggc 2640
gccccctcga ccgacaaaaga aaagagctgg ctgtacaccc tggatcccat cctcatcacc 2700
atcatcgcca tgagctcact gggcgtcctc ctgggggcca cctgtgcagg cctcctgctc 2760
tactgcacct gtctctactc gggcctgagc tccggaagct gcaccacct ggagaactac 2820
aacttcgagc tctacgatgg ccttaagcac aaggtcaaga tgaaccacca aaagtgcctgc 2880
tccgaggcat gacggattgc acctgaatcc tatctgacgt ttcattccag caagaggggc 2940
tggggaagat tacatttttt ttccctttgg aaactgaatg ccataatctc gatcaaacgc 3000
atccagaata ccgaaggat ggacaggaca gaaaagcgag tcgcaggagg aaggagatg 3060
cagccgcaca ggggatgatt accctcctag gaccgcggtg gctaaagtcac tgcaggaaacg 3120
gggctgtgtt ctctgctggg acaaaaacagg agctcatctc ttggggtca cagttctatt 3180
ttgtttgtga gttgtatta ttattattat tattattatt atattttatt tctttggtct 3240
gtgagcaact caaagaggca gaagaggaga atgacttttc cagaatagaa gtggagcagt 3300
gatcattatt ctccgctttc tctttctaata caacactga aaagcaaaagt gtcttttcag 3360
cctttccatc ttacaataa.aaactcaaaa aagctgtcca gctt 3404

FIG. 13C

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FIG. 14A
FIG. 14B
FIG. 14C
FIG. 14E
FIG. 14F

FIG. 14

247	ATG	GAG	AGG	GGG	CTG	CCG	256	CTC	CTC	TGC	265	GCC	GTG	274	GCC	CTC	283	GTC	CTC	GCC	292	CCG
M	E	R	G	L	P			L	L	C	A	V	I	A	L	V			L	A	P	
301	GCC	GGC	GCT	TTT	CGC	AAC	310	GAT	AAA	TGT	319	GGC	GAT	328	ATA	AAA	337	GAA	AGC	346	CCC	
A	G	A	F	R	N			D	K	C	G	D	T	I	K	I		E	S	P		
355	GGG	TAC	CTT	ACA	TCT	CCT	364	GGT	TAT	CCT	373	CAT	TCT	382	CAC	CCA	391	GAA	AAA	400	TGC	
G	Y	L	T	S	P			G	Y	P	H	S	Y	Y	H	P		E	K	C		
409	GAA	TGG	CTG	ATT	CAG	GCT	418	CCG	GAC	CCA	427	TAC	CAG	436	ATT	ATG	445	AAC	TTC	454	AAC	
E	W	L	I	Q	A			P	D	P	Y	Q	R	I	M	I		N	F	N		
463	CCT	CAC	TTC	GAT	TTG	GAG	472	GAC	AGA	GAC	481	TGC	AAG	490	GAC	TAC	499	GAA	GTG	508	TTC	
P	H	H	D	L	E			D	R	D	C	K	Y	Y	D	Y		E	V	F		
517	GAT	GGA	GAA	AAT	GAA	AAT	526	GGA	CAT	TTT	535	AGG	GGA	544	TTC	TGT	553	AAG	ATA	562	GCC	
D	G	E	N	E	N			G	H	P	R	G	K	F	C	C		K	I	A		
571	CCT	CCT	GTT	GTG	TCT		580	TCA	GGG	CCA	589	TTT	CTT	598	ATC	AAA	607	GTC	TCT	616	GAC	
P	P	P	V	V	S			S	G	P	F	L	F	I	K	F		V	S	D		
625	TAC	GAA	ACA	CAT	GGT	GCA	634	GGA	TTT	TCC	643	ATA	CGT	652	GAA	ATT	661	AGG	AGA	670	GGT	
Y	E	T	H	G	A			G	F	S	I	R	Y	E	I	F		K	R	G		
679	CCT	GAA	TGT	TCC	CAG	AAC	688	TAC	ACA	ACA	697	CCT	AGT	706	GTG	ATA	715	TCC	CCC	724	GGA	
P	E	C	S	Q	N			Y	T	T	P	S	G	V	I	K		S	P	G		

FIG. 14A

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733	TTC	CCT	GAA	AAA	TAT	CCC	AAC	AGC	CTT	751	GAA	TGC	ACT	760	TAT	ATT	GTC	769	TTT	GCG	CCA	778
	F	P	E	K	Y	P	N	S	L		E	C	T		Y	I	V		F	A	P	
787	AAG	ATG	TCA	GAG	ATT	ATC	CTG	GAA	TTT	805	GAA	AGC	TTT	814	GAC	CTG	GAG	823	CCT	GAC	TCA	832
	K	M	S	E	I	I	L	E	F		E	S	T		D	L	E		P	D	S	
841	AAT	CCT	CCA	GGG	GGG	ATG	TTC	TGT	CGC	859	TAC	GAC	CGG	868	CTA	GAA	ATC	877	TGG	GAT	GGA	886
	N	P	P	G	G	M	F	C	R		Y	D	R		L	T	I		W	D	G	
895	TTC	CCT	GAT	GTT	GGC	CCT	CAC	ATT	GGG	913	CGT	TAC	TGT	922	GGA	CAG	AAA	931	ACA	CCA	GGT	940
	F	P	D	V	G	P	H	I	G		R	Y	C		G	Q	K		T	P	G	
949	CGA	ATC	CGA	TCC	TCA	TCG	GGC	ATT	CTC	957	TCC	ATG	GTT	976	TTT	TAC	ACC	985	GAC	AGC	GCG	994
	R	I	R	S	S	S	G	I	L		S	M	V		H	Y	T		D	S	A	
1003	ATA	GCA	AAA	GAA	GGT	TTC	TCA	GCA	AAC	1021	TAC	AGT	GTC	1030	TTG	CAG	AGC	1039	AGT	GTC	TCA	1048
	I	A	K	E	G	F	S	A	N		Y	S	V		L	Q	S		S	V	S	
1057	GAA	GAT	TTC	AAA	TGT	ATG	GAA	GCT	CTG	1075	GGC	ATG	GAA	1084	TCA	GGA	GAA	1093	ATT	CAT	TCT	1102
	E	D	F	K	C	M	C	A	L		G	M	E		S	G	E		I	H	S	
1111	GAC	CAG	ATC	ACA	GCT	TCT	TCC	CAG	TAT	1129	AGC	ACC	AAC	1138	TGG	TCT	GCA	1147	GAG	CGC	TCC	1156
	D	Q	I	T	A	S	S	Q	Y		S	T	N		W	S	A		E	R	S	
1165	CGC	CTG	AAC	TAC	CCT	GAG	AAT	GGG	TGG	1183	ACT	CCC	GGA	1192	GAG	GAT	TCC	1201	TAC	CGA	GAG	1210
	R	L	N	Y	P	E	N	G	W		T	P	G		E	D	S		Y	R	E	

FIG.14B

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1219 TGG ATA CAG	1228 GAC TTG	1237 CTT CTG	1246 TTT GTC	1255 GCT GTC	1264 ACA CAG
W I Q	G D L	G L L	F F R	A V T	G T Q
1273 GGC GCC ATT	1282 TCA AAA GAA	1291 ACC AAG AAG	1300 AAA TAT TAT	1309 AAG ACT	1318 TAC AAG ATC
G A I	S K E	T K K	Y Y K	K T	Y K I
1327 GAC GTT AGC	1336 TCC AAC GGG	1345 GAC TGG	1354 ACC ATA	1363 GAA GGA	1372 AAC AAA CCT
D V S	S N G	E D W	I I I	E G N	K P
1381 GTT CTC TTT	1390 CAG GGA AAC	1399 AAC CCC	1408 ACA GAT GTT	1417 GTT GCA	1426 GTA TTC CCC
V L F	Q G N	T N P	T D V	V A	V F P
1435 AAA CCA CTG	1444 ATA ACT CGA	1453 TTT GTC CGA	1462 AAG CCT	1471 GAA ACT GGC	1480 GAA ACT GGC
K P L	I T R	F V R	K P A	T W E	T G
1489 ATA TCT ATG	1498 AGA TTT GAA	1507 TAC GGT	1516 AAG ATA	1525 GAT TAT	1534 CCT TGC TCT
I S M	R F E	V Y G	K I C	D Y	C b1 b2 S
1543 GGA ATG TTG	1552 GGT ATG GTG	1561 TCT GGA CTT	1570 TCT GAC	1579 CAG ATC	1588 ACA TCA TCC
G M L	G M V	S G L	I S D	Q I	T S S
1597 AAC CAA GGG	1606 GAC AGA AAC	1615 TGG ATG CCT	1624 AAC ATC	1633 CTG GTA	1642 ACC AGT CGC
N Q G	D R N	W M P	E N I	L V	T S R
1651 TCT GGC TGG	1660 GCA CTT CCA	1669 CCC GCA CCT	1678 TCC TAC	1687 AAT GAG	1696 TGG CTC CAA
S G W	A L P	P A P	H S Y	I N C	W L Q

FIG.14C

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1705	ATA GAC CTG	1714	GGG GAC GAG	1723	ATC ATC GTG	1732	GGG ATC	1741	ATT CAG	1750	GGG AAG
I	D L G	E E K	I V	G I I	I I Q	G G X					
1759	CAC CGA GAG	1768	AAC AAG GTG	1777	TTC ATG AGG	1786	AAG TTC AAG	1795	GGG TAC	1804	AAC AAC
R	R E N	K V	F H R	K F K	I G Y	S N N					
1813	GGC TCG GAC	1822	TGG AAG ATG	1831	ATC ATG GAT	1840	GAC AGC AAA	1849	AAG GCG	1858	TCT TTT
G	S D W	K M I	M D D	S K R	K A K	S F					
1867	GAG GGC AAC	1876	AAC AAC TAT	1885	GAT ACA CCT	1894	GAG CTG CCG	1903	TTT CCA	1912	CTC TCC
E	G N N	N Y D	T P	E L R	T F P	A L S					
1921	ACG CGA TTC	1930	ATC AGG ATC	1939	TAC CCC GAG	1948	AGA GCC ACT	1957	GGC GGA	1966	CTG GGG CTC
T	R F I	R I Y	P P	R A T	H G G	L G L					
1975	AGA ATG GAG	1984	CTG CTG GGC	1993	TGT GAA GTG	2002	GAA GCC CCT	2011	GGT GGA	2020	CCG ACC ACT
R	N E L	L G C	E V	E b2	T A P	T A G					
2029	CCC AAC GGG	2038	AAC TTG GTG	2047	GAT GAA TGT	2056	GAT GAC GAC	2065	GCC AAC	2074	CAC AGT
P	N G N	L V D	E C D	D D D	Q -A N	C H S					
2083	GGA ACA GGT	2092	GAT GAC TTC	2101	CAG CTC ACA	2110	GGT GGC ACC	2119	GTG CTG	2128	ACA GAA
G	T G D	D F Q	L T G	G G T	T V L	A T E					
2137	AAG CCC ACG	2146	GTC ATA GAC	2155	AGC ACC ATA	2154	CAA TCA GAG	2173	CCA ACA	2182	GGT TTT
K	P T V	I D S	T I Q	S E F	P T Y	G C					

FIG.14D

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2191 AAC TGT GAA	2200 GGC TGG	2209 TCT CAC	2218 ACC TTC	2227 CAC TGG	2236 GAA CAT
N C t	F G W	G S H	T F	C H W	E H D
2245 AAT CAC GTG	2254 CAG CTC AAG	2263 TGG AGT GTG	2272 TTG ACC AGC	2281 AAG ACG GGA	2290 CCC ATT CAG
N H V	Q L K	S V	L T S	K T G	P I Q
2299 GAT CAC ACA	2308 GGA GAT GGC	2317 AAC TTC ATC	2326 TAT TCC CAA	2335 GAC GAA	2344 AAT CAG AAG
D H T	G D G	F I	Y S Q	A D E	N Q K
2353 GGC AAA GTG	2362 CGC CTG	2371 GTG AGC CCT	2380 GTG GTT TAT	2389 CAG AAC	2398 TCT GCC CAC
G K V	A R L	S P	V V Y	Q N	S A H
2407 TGC ATG ACC	2416 TGG TAT	2425 CAC ATG TCT	2434 TCC CAC	2443 GGC ACA	2452 CTC AGG GTC
C M T	F W Y	H M S	S H	G T	L R V
2461 AAA CTG CGC	2470 CAG AAG	2479 CCA GAG GAG	2488 TAC GAT GAG	2497 GTC TGG	2506 ATG GCC ATT
K L R	Y Q K	P E E	Y D Q	V W	M A I
2515 GGA CAC CAA	2524 GGT GAC CAC	2533 TGG AAG GAA	2542 CGT GTC	2551 CTC CAC	2560 AAG TCT CTG
G H Q	G D H	W K E	G R V	L L H	K S L
2569 AAA CTT TAT	2578 CAG GTG ATT	2587 TTC GAG GGC	2596 GAA ATC GGA	2605 GGA AAC	2614 CTT GGT GGG
K L Y	Q Y I	F E G	E I G	G N	L G G
2623 ATT GCT GTG	2632 GAT GAC ATT	2641 AGT ATT AAC	2650 AAC CAC ATT	2659 CAA GAA	2668 GAT TGT GCA
I A Y	D D I	S I N	H I S	Q E	D C A

FIG. 14E

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2677 2686 2695 2704 2713 2722
AAA CCA GCA GAC CTG GAT AAA AAG AAC CCA GAA ATT AAA ATT GAT GAA ACA GGG
K P A D L D K N K N P E I K I D E T G

2731 2740 2749 2758 2767 2776
AGC ACG CCA GGA TAC GAA GGT GAA GGA GGT GAC AAG AAC ATC TCC AGG AAG
S T P G Y E G E G E G D K N I S R K

2785 2794 2803 2812 2821 2830
CCA GGC AAT GTG TTG AAG ACC TTA GAT CCC ATC CTC ATC ACC ATC ATA GCC ATG
P G N V L K T L D P I TM I T I I A M

2839 2848 2857 2866 2875 2884
AGT GCC CTG GGG GTC CTC CTG GGG GCT GTC TGT GGG TGT CTG GTG CTG TAC TGT GCC
S A L G V L L G A V C G G V V L Y C A

2893 2902 2911 2920 2929 2938
TGT TGG CAT AAT GGG ATG TCA GAA AGA AAC TTG TCT GCC CTG GAG AAC TAT AAC
CTM W H cyto G M S E R N L S A L E N Y N

2947 2956 2965 2974 2983 2997
TTT GAA CTT GTG GAT GGT GTG AAG TTG AAA AAA GAC AAA CTG AAT ACA CAG AGT
F E L V D G V K L K K D K L N T Q S

3001 3010
ACT TAT TCG GAG GCA TGA 3' (SEQ ID NO: 1)
T Y S E A * (SEQ ID NO: 2)
cyto

```

FIG.14F

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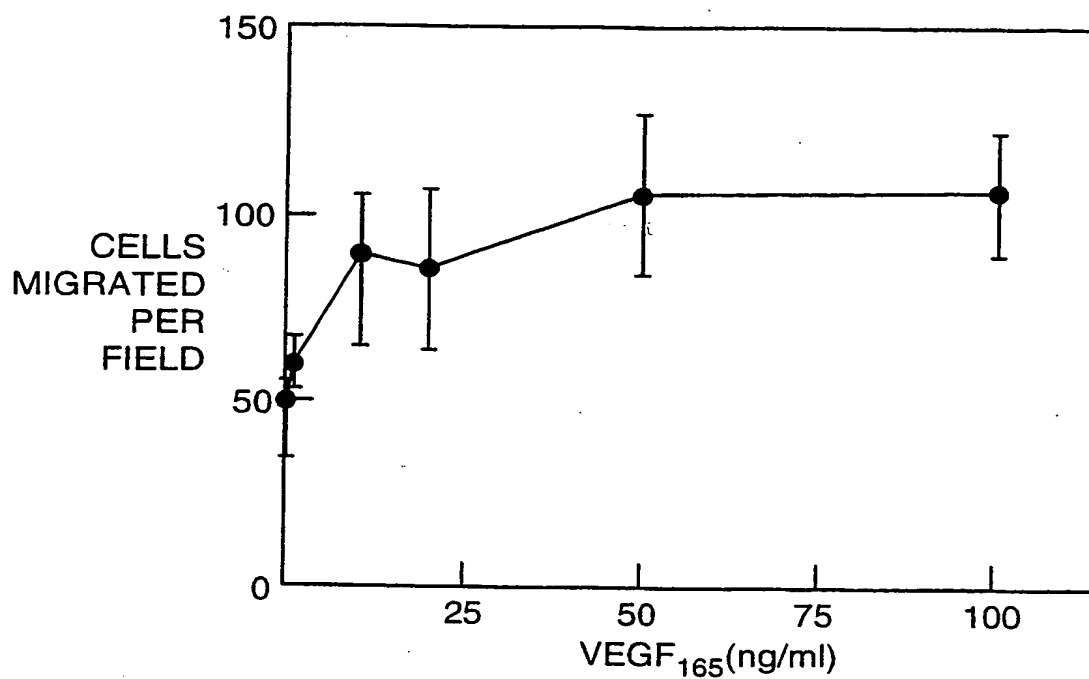


FIG. 15A

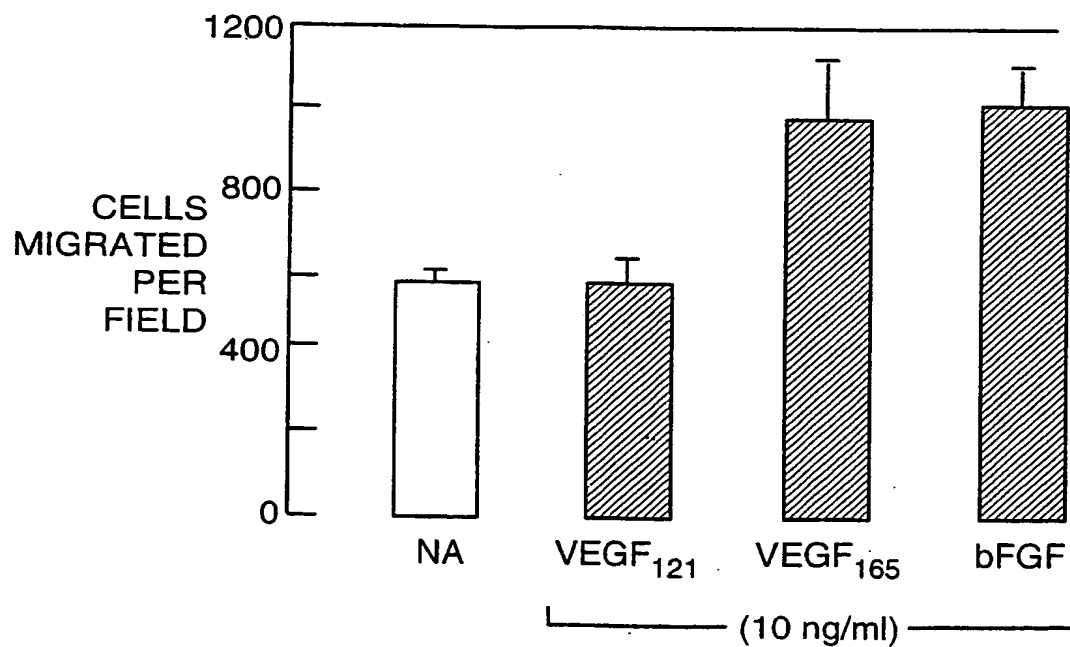


FIG. 15B

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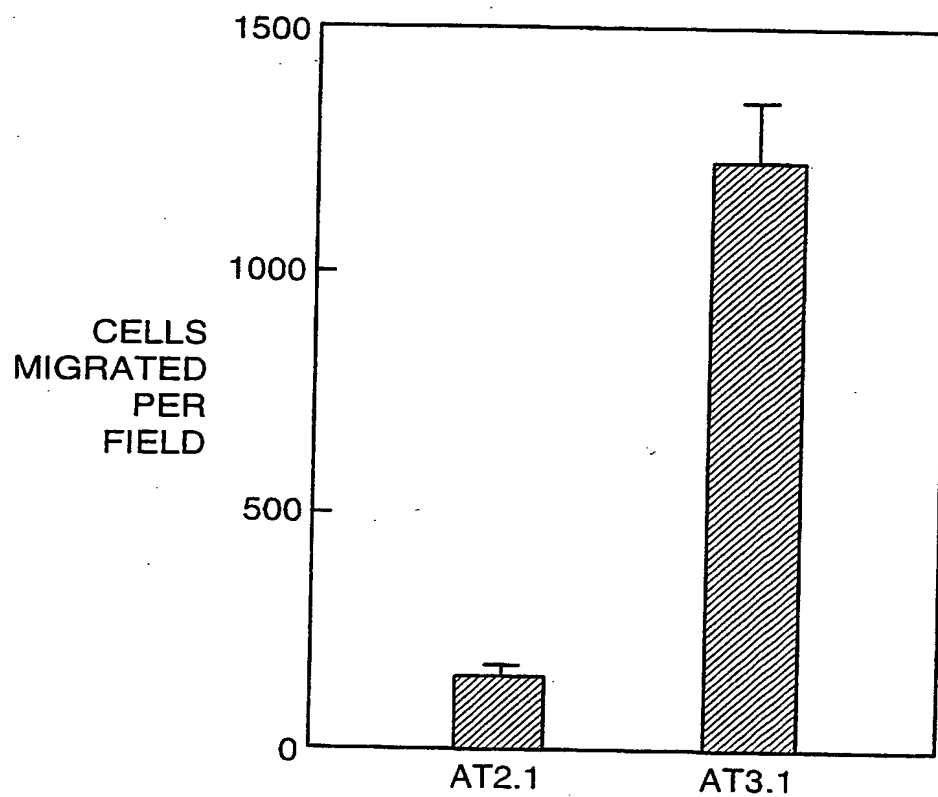


FIG. 16A

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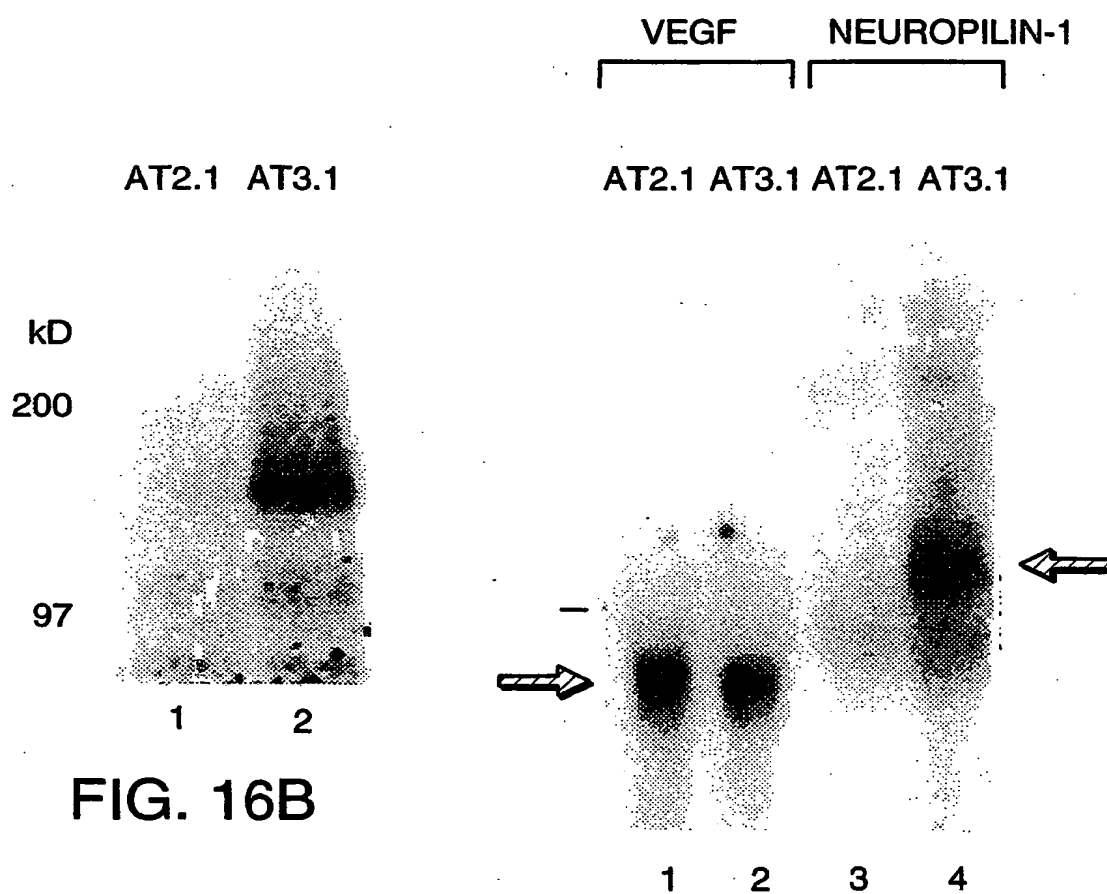


FIG. 16B

FIG. 16C

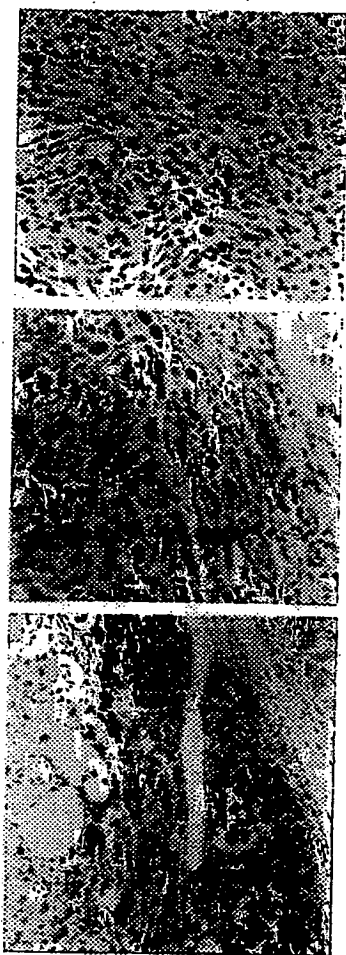


FIG. 17A FIG. 17B FIG. 17C

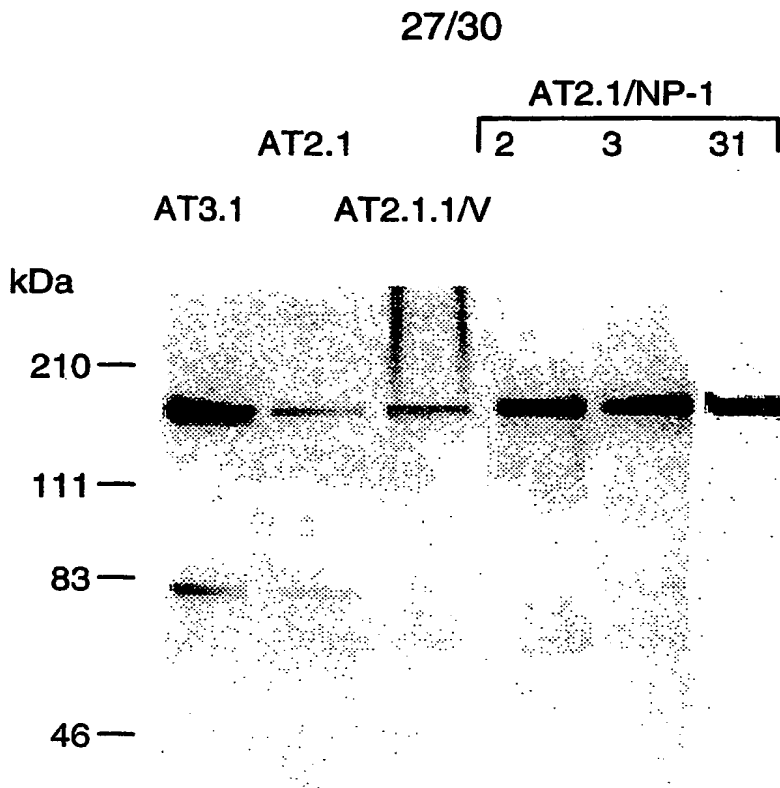


FIG. 18A

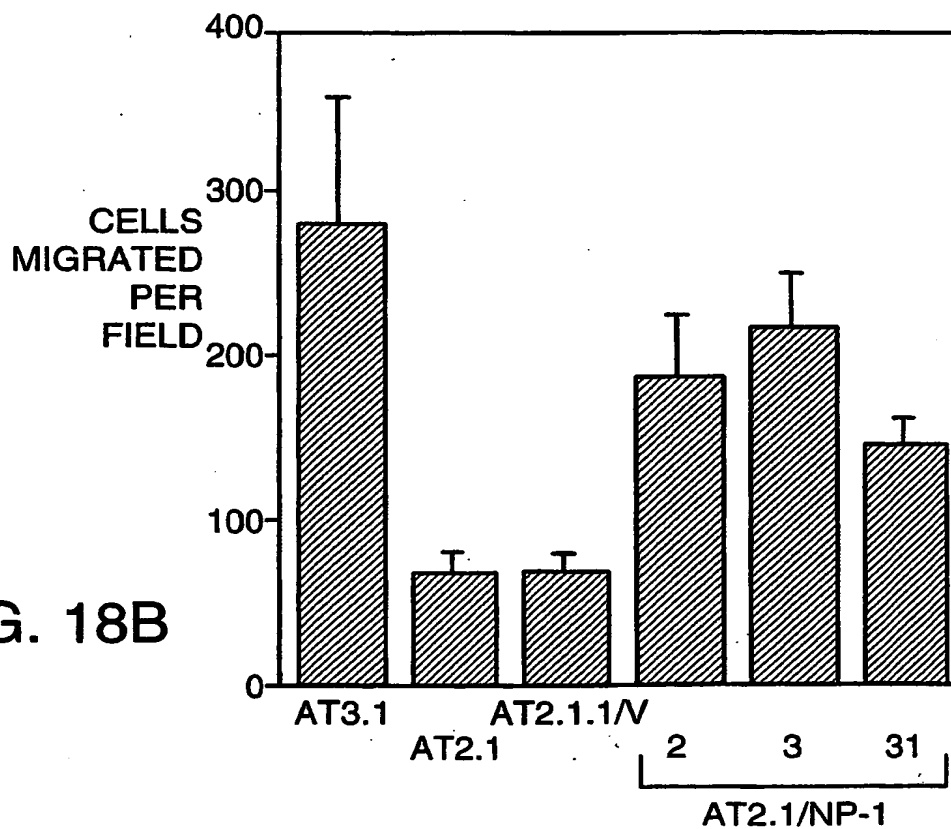


FIG. 18B

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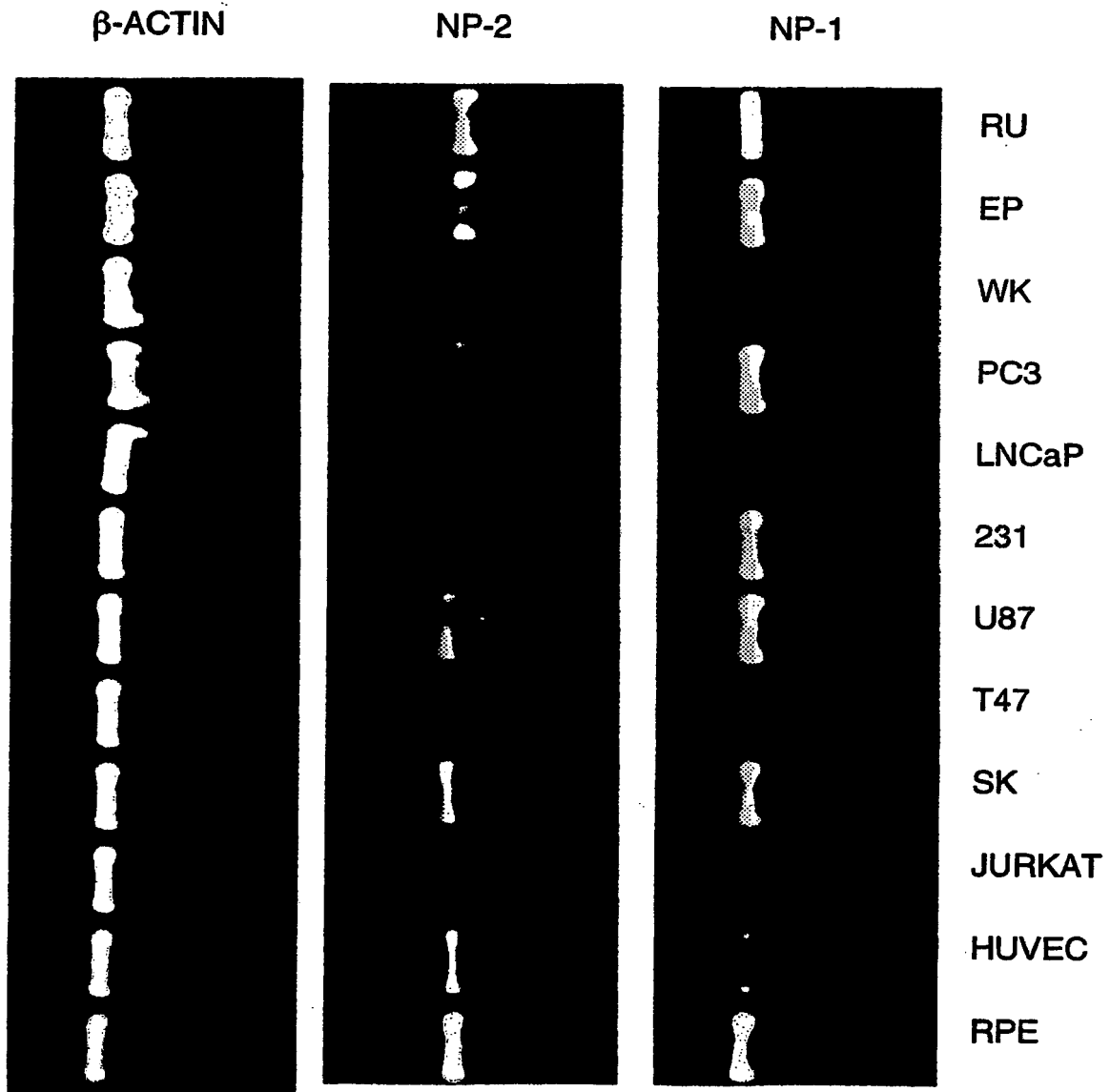


FIG. 19

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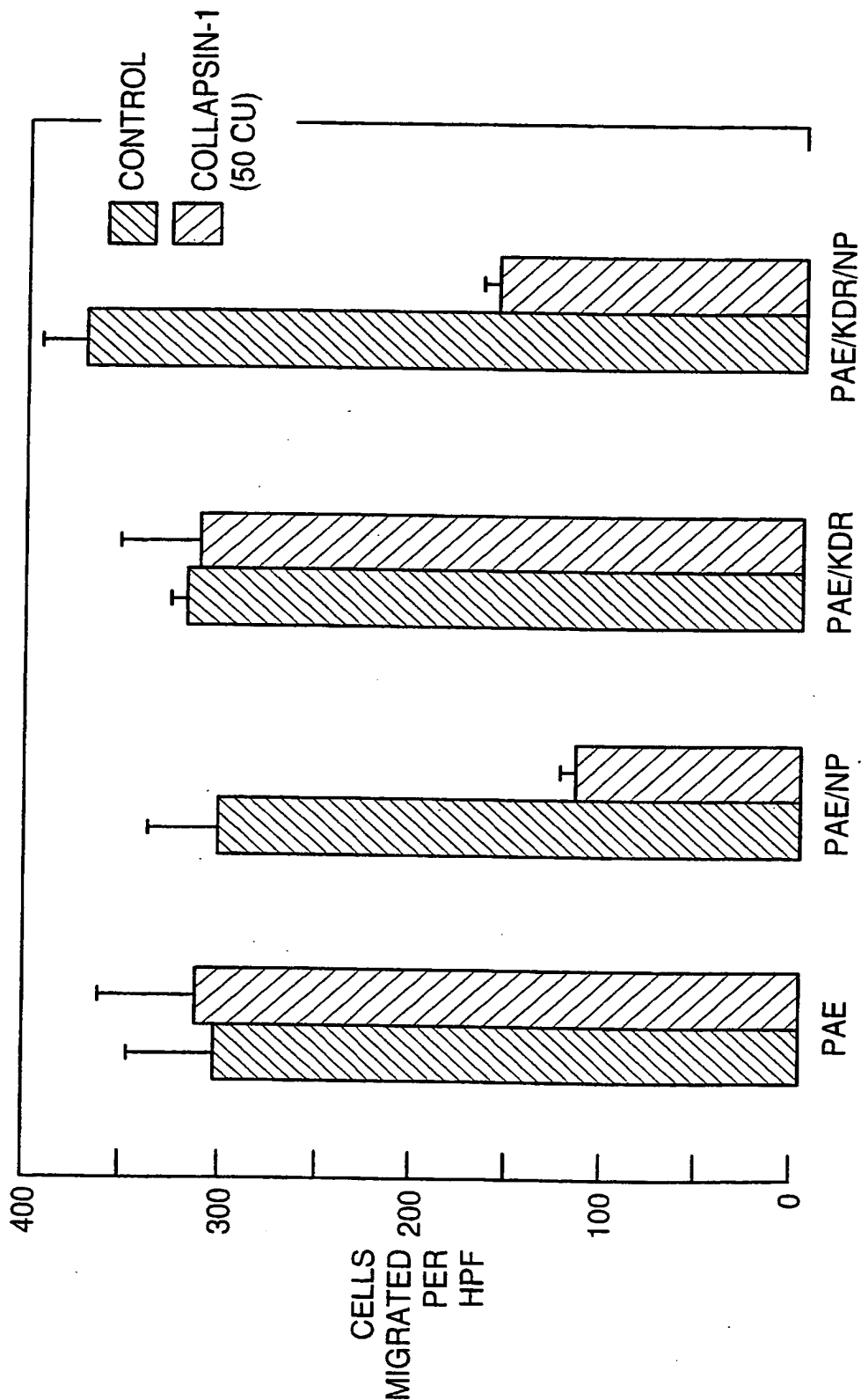


FIG. 20

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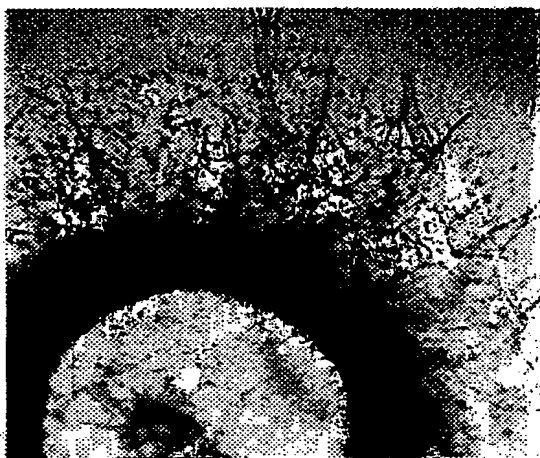


FIG. 21A

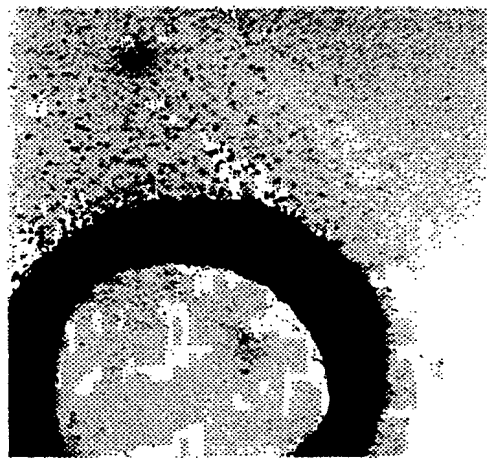


FIG. 21B



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : C07K 16/22, A61K 39/00	A3	(11) International Publication Number: WO 99/29729 (43) International Publication Date: 17 June 1999 (17.06.99)
(21) International Application Number: PCT/US98/26114 (22) International Filing Date: 9 December 1998 (09.12.98) (30) Priority Data: 60/069,155 9 December 1997 (09.12.97) US 60/069,687 12 December 1997 (12.12.97) US 60/078,541 19 March 1998 (19.03.98) US (71) Applicant (for all designated States except US): CHILDREN'S MEDICAL CENTER CORPORATION [US/US]; 320 Longwood Avenue, Boston, MA 02115 (US). (72) Inventors; and (75) Inventors/Applicants (for US only): KLAGSBRUN, Michael [US/US]; 22 Berwick Road, Newton, MA 02159 (US). SOKER, Shay [IL/US]; 92 Beals Street, Brookline, MA 02446 (US). MIAO, Hua-Quan [CN/US]; Apartment 8, 50 Babcock Street, Brookline, MA 02446 (US). TAKASHIMA, Seiji [JP/JP]; 1st Dept. of International Medicine, Osaka University School of Medicine, 2-2 Yamadaoka Suita, Osaka 565-0871 (JP). (74) Agents: RESNICK, David, S. et al.; Peabody & Brown, 101 Federal Street, Boston, MA 02110-1832 (US).	(81) Designated States: AU, CA, JP, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). Published <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i> (88) Date of publication of the international search report: 15 July 1999 (15.07.99)	
(54) Title: ANTAGONISTS OF NEUROPILIN RECEPTOR FUNCTION AND USE THEREOF		
(57) Abstract		
<p>The present invention relates to antagonists of neuropilin receptor function and use thereof in the treatment of cancer, particularly metastatic cancer, and angiogenic diseases.</p>		

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INTERNATIONAL SEARCH REPORT

International Application No.
PCT/US 98/26114

A. CLASSIFICATION OF SUBJECT MATTER

C 07 K 16/22, A 61 K 39/00

According to International Patent Classification (IPC) or to both national classification and IPC: 6

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C 07 K, A 61 K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X, D	HANG CHEN et al. Neuro- pilin-2, a Novel Member of the Neuropilin Family, Is a High Affinity Receptor for the Semaphorins Sema E and Sema IV but Not Sema III. Neuron, September 1997, Vol. 19, No. 3, pages 547- 559 (cited in the application).	7, 8
A	Summary, page 553 right column - page 556, left column, page 558, left column "Binding Analysis" (cited in the application).	1-6, 17
X	KOLODKIN, A.L. et al. Neuropilin is a Semaphorin III Receptor. Cell, August	7, 8

☒ Further documents are listed in the continuation of box C.

☐ Patent family members are listed in annex.

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Date of the actual completion of the international search

08 April 1999

Date of mailing of the international search report

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WENIGER e.h.

INTERNATIONAL SEARCH REPORT

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PCT/US 98/26114

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	1997, Vol. 90, No. 4, pages 753-762 (cited in the application). Summary, results, page 760, left column, paragraph 2 - page 761, right column, paragraph 1 (cited in the application). ---	1-6, 17
A	Kim J.K. et al. Inhibition of vascular endothelial growth factor-induced angiogenesis suppresses tumour growth in vivo. Nature, April 1993, Vol. 362, No. 6423, pages 841-844, the whole document (cited in the application). ---	1-8, 17
A	KLAGSBRUN, M. et al. VEGF/VPF: the angiogenesis factor found? Current Biology, January 1993, Vol. 3, No. 1, pages 699-702, the whole document. ---	1-8, 17
A	Poltorak, Z. et al. VEGF145, a Secreted Vascular Endothelial Growth Factor Isoform That Blinds to Extracellular Matrix. The Journal of Biological Chemistry, March 1997, pages 7151-7158, the whole document (cited in the application). -----	1-8, 17

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 98/26114

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

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because they relate to subject matter not required to be searched by this Authority, namely:

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2. ☐ Claims Nos.:
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3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

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2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
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4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

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- ☐ The additional search fees were accompanied by the applicant's protest.
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